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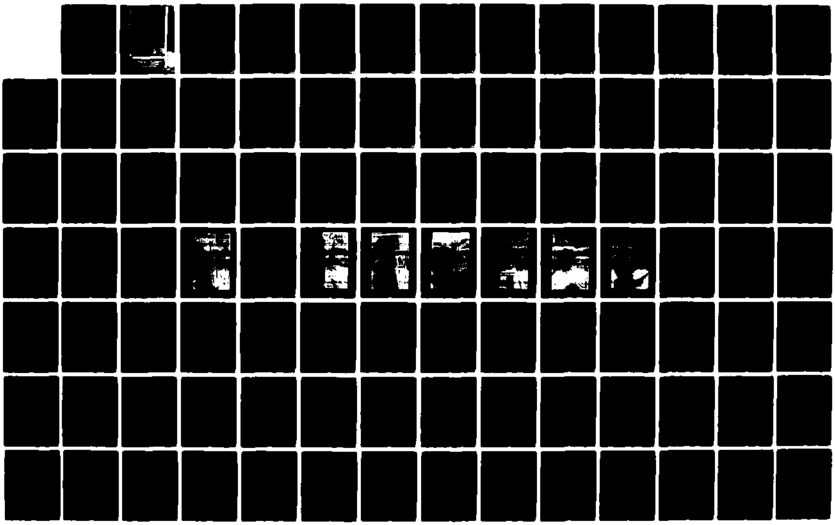

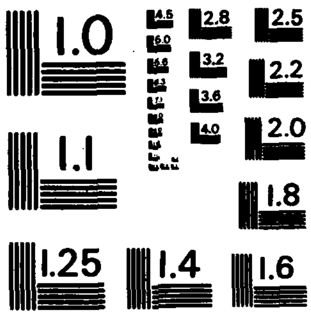

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THE USE OF CYCLONE MODELING IN THE ERECTION
OF PRECAST SEGMENTAL AERIAL CONSTRUCTION

A SPECIAL RESEARCH PROBLEM

Presented to

The Faculty of the School of Civil Engineering

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by

Scott Cleveland

In Partial Fulfillment

of the Requirements for the Degree

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I wish to express deep appreciation to my wife, Marcia, without whose faith, support, encouragement, and love this work would not have been possible.

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ABSTRACT

The intent of this work is to analyze two methods of obtaining activity duration data in the field for use in the CYCLONE modeling program for determining construction productivity. One method is the traditional stopwatch-type study while the other is utilization of time-lapse photography. The construction activity which will be observed is the erection of an aerial guideway for the Metropolitan Atlanta Rapid Transit Authority (MARTA) rail line.

The aerial guideway is being built using precast post-tensioned segmental concrete construction. This method of bridge construction or elevated span construction has proven to be more economical than more conventional methods of construction. One of the primary reasons for lower cost is the speed at which precast post-tensioned segmental concrete construction can be put in place.

Field data for the erection procedure will be input into the CYCLONE model to obtain a production rate to be compared to actual field production.

CHAPTER I

INTRODUCTION

Productivity in the construction industry is a major concern of contractors and of the organizations which provide funding for construction projects. Whether a construction project is large or small, productivity plays a part in the amount of profit realized on a project, and in completing the work on schedule or behind schedule. "Though it is difficult to measure, the Congressional Budget Office estimates that growth in construction productivity since the mid-1960's has been negative."[1] How can one attempt to measure that productivity?

Productivity is often viewed from the perspective of observing the output of a crew; in other words, how active the crew is during the work day. This approach is useful in determining the effectiveness of the crew; however, idleness of the crew or of individual crew members is not an indicator that the crew is wasting time. Often the crew or a crew member is waiting due to the non-availibility of materials, tools, or equipment.[2] Thus a crew may be non-productive due to circumstances beyond the control of the individual crew members. "People generally want to produce and feel productive. They will attempt to appear productive and 'do work' even if it isn't 'effective work.'"[3]

Management of construction projects requires some type of planning and control. The use of network analysis methods, such as the Critical Path Method (CPM), Precedence networks, or Program Evaluation and Review Technique (PERT), among others provide a means for organizing, planning and scheduling construction work over a period of time. The individual activities in the network represent pieces of the project to be completed and can be many or few, depending on the complexity of the construction project and the level of detail desired in controlling the project.

In the planning and estimating phase, prior to the initiation of work on the construction site, durations (usually in days) are assigned to the activities in the network. These durations are based on historical data and previous experience for similar type work. If careful planning has been done, the time duration estimates will also reflect what is known about the project work site. For example, the historical data may be based on work that was performed in open areas with fairly level terrain, whereas the new project site may be in a heavily forested, hilly area.

By associating the estimated times with the network activities, a rate of production for each activity is assumed. This can be equated to units per week, units per day, etc.

Most often the terminology used at the job site level is "output units per manhour."[4]

While the use of CPM and other networking methods allow the project to be scheduled and controlled, it affords no insight into reasons why a particular activity may be ahead of schedule or be falling behind schedule. Prior to start up of a project, or even after a project has begun, but prior to initiation of work on activities later in the project, the activities can be analyzed with respect to methods of accomplishing the work, utilization of equipment and manpower, and availability of materials, among others. This allows the productivity of the activities to be reviewed and updated if necessary.

Construction projects are generally comprised of activities that are repetitive in nature. Analyzing the steps involved in completion of an activity allows management to observe the sequence of events which transpires. In this way, planning can be accomplished as to the type and quantity of resources (labor, equipment, tools, materials, etc.) required to complete the activity.

Preconstruction planning of activities and their estimated production rates involves the use of "engineering intuition and scientific guesses."[5] This is a combination of past experience in the construction field, historical data recorded from similar work, and the use of published estimating guides for the construction industry.

Analysis of construction activities can also occur while the work is in progress. By comparing the production of the ongoing work with the estimated or assumed production which was determined prior to work being initiated, an assessment of the status of the activity can be made and corrective action taken to speed up or slow down the work.

Providing a production rate for work in progress requires some method of obtaining data (specifically time durations) relating to the various activities on a network. The construction activity should be divided into various work components to allow times to be observed and recorded for the components which complete the activity. For example, an activity identified as "PLACE FILL" may consist of several components such as: (1) load truck; (2) truck travel and dump; (3) loader obtain load; (4) spread fill; and (5) compact fill, etc. The number of components of an activity depends on the level of detail desired as to the production rates of equipment or crews.

Various methods exist for obtaining data on the productivity of construction operations. One approach that measures the level of activity of the work force is based on activity-sampling or work-sampling procedures.[6] Two such techniques are the field-rating method[7] and the five-minute rating technique.[8] As attempts are made to control the cost of large construction projects, work sampling techniques are receiving increased emphasis as a method of activity measurement.[9]

The use of stopwatch studies[10] and time-lapse motion pictures[11] to record activities and times associated with various work tasks are other methods in use.

Once time durations are associated with the various components of a construction activity, there remains the method to utilize in determining the productivity of the system. One technique involves the use of the Method Productivity Delay Model (MPDM) developed by Dr. James J. Adrian which provides a practical method of measuring, predicting, and improving productivity.[12] A second technique which is suited for the analysis of repetitious and cyclic movement of productive units through a construction activity is called CYCLONE, which was developed by Dr. Daniel W. Halpin and is derived from the words CYCLic Operations NEtwork system.[13]

The objective of this paper is to look at productivity in the construction industry in terms of methods of obtaining times for productivity studies. This is necessary in establishing what is to be considered productive time or non-productive time on a construction project. A consistent method of obtaining time data must be utilized. The use of stopwatch type studies and time-lapse photography will be investigated by actual field observations of a construction project involving the erection of an aerial guideway consisting of precast segmental sections. The data obtained from field observations will be utilized with the modeling capabilities of the CYCLONE technique to obtain production values. The "modeled" production values can then be compared to actual field production for determination of the validity of the computer simulation process. The use of time-lapse photography versus stopwatch studies will be evaluated as to their value in obtaining time durations for productivity analysis using CYCLONE.

Chapter I has consisted of an introduction to the concept of productivity in the construction industry, a brief overview of the methodology available to analyze production, and the stated purpose of this paper. Chapter II will delve more deeply into the state of the art in construction industry productivity, methods of time measurement, and will explore the concept of segmental bridge construction, its growing use in the construction industry, and its effect on production. Chapter III will discuss the Metropolitan Atlanta Rapid Transit Authority (MARTA) project sites where field data was obtained and a description of the erection operation. The methodology used in analyzing and converting the data for use in the CYCLONE program will be presented in Chapter IV. Conclusions based on the findings in this report will be presented in Chapter V.

CHAPTER II

STATE OF THE ART

Construction Industry Productivity

Construction, a 100-billion dollar-plus industry, which employs over ten percent of the work force of this country and contributes over ten percent to the gross national product of the United States, is the largest industry in the United States.[14] As the nation's largest industry, it would be natural to assume that the construction industry has enjoyed a high rate of productivity over the years. Historical data does indicate a three percent annual increase in construction productivity from 1948 to 1969, but shows a marked drop in productivity from 1969 until the late 1970s, at which time it had dropped to the level of productivity experienced in the late 1950s.[15]

This decrease in productivity has been accompanied by a steady increase in construction labor costs on large industrial projects over a period of the last fifteen years.[16] This increase in labor costs has not been limited to large industrial projects. Increases in construction costs can also be attributed to other factors such as increased regulatory requirements, and a dramatic increase in the cost of borrowing money.[17] All of these factors: an increase in labor costs, regulations requiring environmental impact statements prior to construction, extremely high interest rates on borrowed money, and others have focused the attention of those in the construction industry on the fact of decreasing or stagnant productivity in the area of construction. A survey of the top 400 Engineering News Record contractors conducted by James Choromokos, Jr. and Keith E. McKee in 1978-1979 provided an overall indication that contractors recognized the need for productivity improvement in all phases of construction, from the main office to the construction site.[18]

The focus of this paper is on the job site and will not deal with productivity enhancement in the office setting of planning, scheduling, marketing, engineering, procurement, etc. The job site is the location of the "hands-on" construction activity. Construction operations are accomplished by crews performing their jobs within the basic work elements of an administrative aspect (information, equipment, tools, energy, materials, and a work place) provided by management; a mental and physical environment (which impacts on how a crew performs); and the work methods utilized along with the individual's skills and motivation.[19] "The greatest cost reductions and improvements in speed and efficiency on construction projects have come when management analyzes work methods, administrative constraints, and environmental constraints and how these affect the crew-level work in the field."[20]

Time Measurement

The concept of productivity engineering is one hundred years old, having originated when Frederick Taylor developed time study in steel mills in the 1880s, and continuing to evolve with the use of motion study by Frank Gilbreth to improve concrete and bricklaying jobs at the turn of the century.[21] As such, Gilbreth was the first to extensively apply the use of work improvement techniques in construction.[22] Daniel Hauer was another work study pioneer in the early 1900s who applied work improvement methods to construction.[23] Today with more attention being focused on construction productivity, the book, Methods Improvement for Construction Managers, by Henry W. Parker and Clarkson H. Oglesby, is considered by some to be " . . . the only major summary of knowledge on productivity engineering for construction."[24]

Parker and Oglesby define work improvement as " . . . the analysis of all the facets of a project or task in order that it may be done with less effort, at less cost, with greater safety, and at a faster rate."[25] By effectively applying the concept of work improvement to construction the end result is to improve productivity, not by working harder but by working smarter.[26]

Planning of a construction project is accomplished prior to the initiation of work by dividing the project into logical components of work and further dividing those components into smaller activities for the level of detail desired on the project. Many construction activities are repetitious and once underway can be analyzed with a view toward an increase in productivity. With this in mind, Parker and Oglesby outlined a step-by-step procedure[27] as follows:

1. Record the job as it is being done, by one or more of these methods
   a. Observation
   b. Stopwatch studies
   c. Time-lapse photography
2. Analyze every detail of the present method using
   a. Analytical thinking
   b. Flow-process charts
   c. Crew-balance studies
   d. Aids such as models
3. Devise new methods by
   a. Asking "Why, what, where, when, who, how?"
   b. Holding round-table discussions; possibly using "brainstorming" techniques
   c. Soliciting ideas from management, superintendents, foremen, and tradesmen
4. Implement the better method by
   a. Selling the idea to boss and workmen
   b. Putting the new method into practice

Implementation of methods improvement or work improvement requires the gathering of data. Techniques for data collection include stopwatches, time-lapse photography, and work sampling.[28] Wallace J. Richardson defines work sampling as " . . . a productivity measurement technique used for the quantitative analysis, in terms of time of the activities of men or equipment."[29] While this technique is fairly simple and inexpensive, and provides an overall indication of the distribution of the activities of the workers, it does not provide the essential information necessary for productivity or methods improvement.[30]

The method of using stopwatch studies involves an individual with a stopwatch observing an activity and recording the time involved in completion of the particular activity or completion of a work cycle within an activity. Marvin E. Mundel outlines the three methods[31] as:

1. CONTINUOUS TIMING

In continouous timing the watch runs continuously throughout the study. The watch is started at the beginning of the element of the first cycle being timed, and is not stopped until the study is completed. At the end of each element the time is recorded. The individual element times are obtained by successive subtractions after the study is completed. This is one of the most commonly used methods.

2. REPETITIVE TIMING

In repetitive, or snapback, timing, the watch is started at the beginning of the first element of the first cycle being timed, and is simultaneously read and snapped back to zero at the completion of this, and each subsequent, element. This allows the element times to be entered directly on the time study sheet without the need for subtractions. Consistent over- and under-reading of the watch will cause cumulative errors with this method but would not affect the continuous method. Also, considerable manipulation of the watch is required. Many labor groups look upon the repetitive method as being highly liable to error. With extremely short elements, any errors that occur may represent large percentages of the elements. Some time study men use another watch to accumulate the total time so as to check these errors. However, in competent hands the repetitive method is successful enough to make it widely used.

3. ACCUMULATIVE TIMING

Accumulative timing is a method involving either two or three watches. In one method, two watches are mounted in a special holder with a mechanical linkage between the watches. For continuous timing, the linkage is manipulated so that at the end of each element one watch is stopped and the other restarted. The stopped watch is read, and element times are obtained later by subtracting alternate readings. For repetitive timing, the stopped watch is returned to zero after being read, and elementtimes are read directly. An effective three-watch accumulative mechanism is also used. . . . The watches used on this board function as follows. The first press on the crown returns the watch to zero, the second press starts it running, the third press stops it at the reading. . . . Each press on the lever, which presses the crowns of all three watches, stops one watch, returns one to zero, and starts another watch running. In this fashion, the time for each element may be read, without subtraction, directly from a stopped watch. For short elements the board is very useful. A fourth watch is sometimes added as a check on the total elapsed time. It should be noted that a single digital electronic timer is available which replaces all four watches while being used in the accumulative mode.

Time-lapse photography is the other method mentioned as useful in gathering data for productivity measurements.

Over a period of many years, the time-lapse camera has proved an excellent means of collecting information and data for work-improvement studies. Time-lapse photography has the advantage of being relatively inexpensive, able to record the activities of a large number of components (men and machines) at one time, able to record interrelationships among these compnents, and useful as a permanent, easily understandable record. It has also proved extremely valuable as a means by which foremen and supervisory personnel can study and improve their jobs without resortingto the detailed form work-improvement techniques. Other applications, such as teaching, safety studies, and descriptive presentations, have been equally effective. The films have also been effective as a means for recording effective techniques for use on other projects.[32]

Development of Super 8-mm film and equipment allow its use for time-lapse photography. Time-lapse photography involves the taking of individual pictures on movie film at intervals of one, two, three, or four seconds, depending on the extent of detail desired in the work recorded over extended periods of time.[33] Once the film is developed, it can be viewed as many times as necessary, and at varying speeds, to permit an individual to extract the desired time information or other data from the construction activity which was filmed.

John Fondahl, who was involved in research using time-lapse photography on construction activities in the late 1950s, discovered that time-lapse photography provides advantages to the methods analyst including: ease of recording and analysis compared to stop watch studies, precise recording of simultaneous crew and machine activities, wealth of detail preserved, and the useful permanent record of film.[34]

To provide some background on the concept of time and motion studies, investigation was made into what previous research has been performed in the areas of construction productivity and time and motion studies.

Roy Pilcher has written several books concerning construction management and cost control and concludes that it is worthwhile for a construction manager to understand the principles of work study and to be able to methodically think through the work activities in a construction project.[35]

He advises that an evaluation of the economic benefits of a work study should first be considered, and if it appears that savings can be made, then the method of work study should be selected. Among the work study methods presented are activity sampling, flow process charting, predetermined motion time systems, the use of time-lapse photography, and a payment-by-results scheme.[36]

Another English author in the field of construction management, R. E. Calvert, also includes a chapter on work study in his book, Introduction to Building Management. Calvert equates construction productivity " . . . as the measured value of construction, divided by the total cost of labour, plant and materials."[37] He further discusses examples of how productivity can be influenced by technical, economic or human factors and how certain management techniques of work measurement and method study have evolved to analyze construction activities to improve productivity.[38]

R. Oxley and J. Poskitt define work study as " . . . the provision of factual data to assist management in making decisions and to enable them to utilize with the maximum of efficiency all available resources (i.e., labour, plant, materials and management) by applying a systematic approach to problems instead of using intuitive guesswork."[39] They then break work study into method study and work measurement and further describe the interrelationships of each.

Various studies have been conducted on construction productivity. The research includes management impact on productivity, the use of Foreman-Delay Surveys, the affect of organized labor on productivity, motivation of construction workers, and other factors affecting productivity.

Robert D. Logcher and William W. Collins in their paper "Management Impacts on Labor Productivity" studied the impact of management's influence on labor at the job site level by analyzing factors such as: "(1) The level of on-site management and coordination; (2) workmen's job security; (3) labor experience; (4) workmen's long-term pacing; (5) delays; and (6) breaks in the work."[40] Their approach utilizes job site observations for gathering data. The use of time-lapse photography is mentioned as a means of gathering data for work sites which afford the opportunity.

John D. Borcherding has done considerable research regarding productivity on construction projects. In a study conducted on two conventional power plants, two chemical refineries and a paper mill, Borcherding compared the results of interviews with construction personnel on these projects with those of construction personnel on commercial building projects.[41] His findings pointed to improved methods of management in the areas of organization structures, overtime, motivation, and change order strategy in order to improve productivity on large construction projects.[42] Another study conducted by Borcherding and Douglas F. Garner involved the use of " . . . a craftsman questionnaire survey, a general foreman questionnaire survey, separate craftsman and foreman group interviews, and a site characteristics checklist"[43] on eleven nuclear power plant sites and one nonnuclear power plant construction site. The recommendations from this study relate to establishing a cooperative atmosphere among all levels and parties involved and providing adequate support and assistance to the work force in order to improve motivation and productivity.[44]

Borcherding also collaborated with Clarkson H. Oglesby in studying " . . . the relationships between job satisfaction, job dissatisfaction, and construction productivity."[45] Again in this survey, interviews were conducted with construction personnel and the responses evaluated to determine what effect human relationships have on construction productivity.

A study conducted by Nancy Samelson and John D. Borcherding at five different nuclear plant construction sites was designed to " . . . understand the most significant factors reducing the morale of lower-level supervisors and craftsmen on large energy production construction projects."[46] The survey identified factors affecting productivity such as rework, waiting for decisions, and waiting for materials and tools.[47]

In the early 1970s, Charles R. Schrader performed research in the area of labor cost control at the field supervision level by the use of scientific management principles. He contended that the cost of construction productivity could be controlled by the use of six basic techniques of scientific management: (1) modeling; (2) preplanning of construction activities; (3) structured questioning of the proposed method of work; (4) detailed planning and budgeting of manhours for each construction operation; (5) maintaining a detailed schedule; and (6) control of the trades working on the activities, and that to follow this plan would require the use of such techniques as time-lapse photography, CPM, etc.[48]

Harold E. McNally and John A. Havers compiled a study entitled "Labor Productivity in the Construction Industry" in which they listed what they believe are the most significant factors affecting labor productivity: (1) environmental factors; (2) labor availability factors; (3) job factors; and (4) management factors.[49] They further report that more emphasis needs to be placed on improving productivity by the use of such methods as random observation studies, time and motion studies, multiple activity charts, phot graphic analysis, applying psychological factors, and keeping the work area from becoming overcrowded.[50]

Another angle on the subject of construction productivity is the resistance of labor unions to the use of methods improvement studies by owners and contractors in an attempt to increase productivity and reduce costs. H. Randolf Thomas, Jr. and Mason P. Holland reviewed nine case studies in which labor unions had submitted grievances to binding arbitration which had arisen due to some form of methods improvement study initiated by management (traditional time studies, closed-circuit television surveillance, and videotape time studies).[51]

Richard L. Tucker, David F. Rogge, William R. Hayes, and Frank P. Hendrickson introduced a new method of measuring construction site performance entitled foreman-delay surveys (FDS). In their paper, the custom " . . . of using surveys of construction foremen to make a qualitative and quantitative determination of the job factors resulting in lost time, and the subsequent use of this information as a management tool for the reduction of the magnitude of these factors and the improvement of worker morale is investigated."[52] Comparison of production rates and work sampling observations to the usefulness of FDS for performance measurement and productivity improvement at construction sites is evaluated in another paper by Rogge and Tucker.[53]

Frank C. Wardwell authored an article published in 1939 concerning time studies of heavy construction operations on several Tennessee Valley Authority (TVA) projects. Extensive use of time study groups using the stopwatch recording method concluded that the use of time studies can prove profitable on: (1) comparisons of equipment performance; (2) operations of a continuous or frequently recurring nature; (3) selection of the proper operating group; and (4) quick determination of unit costs for estimating or comparing construction methods.[54]

The application of time and motion studies to the housing construction industy was studied in the early 1960s under a project called Time and Methods Analysis Program (TAMAP) which utilized stopwatch studies and time-lapse photography for data collection.[55] R. J. Johnson, then director of research and technology of the National Association of Homebuilders, presented a paper on the TAMAP study to the third CIB Congress in Copenhagen in 1965, in which he concluded that the TAMAP project demonstrated that by studying a construction operation and implementing cost saving ideas obtained from the study, productivity can be substantially improved.[56]

The concept of using work study to improve productivity in the building industry, with the emphasis on housing construction, in India is presented in the paper, "Work Study and Industrialization in the Building Industry," by H. V. Mirchandani and J. S. Sharma.[57]

John W. Fondahl has conducted a good deal of research on methods study techniques as a means of assisting construction management personnel in improving productivity on construction sites. In his article "Photographic Analysis for Construction Operations," Fondahl demonstrates how the use of time-lapse photography can be used for collection of data which is further analyzed in order to improve the productivity of construction operations.[58] A separate article by Fondahl describes a study he conducted on the erection of falsework for an elevated highway structure in which he used time-lapse photography to record the activity and later extracted time data from the time-lapse film.[59]

Howard B. Sprinkle's paper regarding time-lapse photography, "Analysis of Time-Lapse Construction Films," outlines several ways that various forms of useful management statistics and charts may be obtained from the data collected by the use of time-lapse photography.[60] His conclusion is that " . . . photographic means have definite advantages over conventional data collection methods."[61]

CYCLONE

CYCLONE involves the breaking down of a construction activity into a series of repetitive components that link the cyclic movement or sharing of resources and individual time durations for completion.[62] The name CYCLONE is derived from the term CYCLic Operations NEtwork[63] developed by Dr. Daniel W. Halpin as a method for modeling construction operations as a means of managing job site activities.

A construction project is a dynamic operation involving various activities continuously moving throughout the job site. These activities involve a cyclic movement of resources (labor, materials, equipment) in producing an end product. The dividing up of a construction activity into resources used, movement or flow of the resources through the activity, and the components of work, and subsequently analyzing the interaction of the components provides the basis for CYCLONE modeling.

> The CYCLONE approach consists of taking a construction operation and breaking it down into a series of repetitive activities that involve the cyclic movement or sharing of resources and for which time durations can be estimated. Its intent is to focus attention on how, rather than when, a particular operation is to be accomplished by examining the basic components of the process under consideration and the interaction of these components in a dynamic situation. In a CYCLONE diagram or model, units flow along prescribed processing lines. These flow units may be resources or the end product that the construction process is producing.[64]

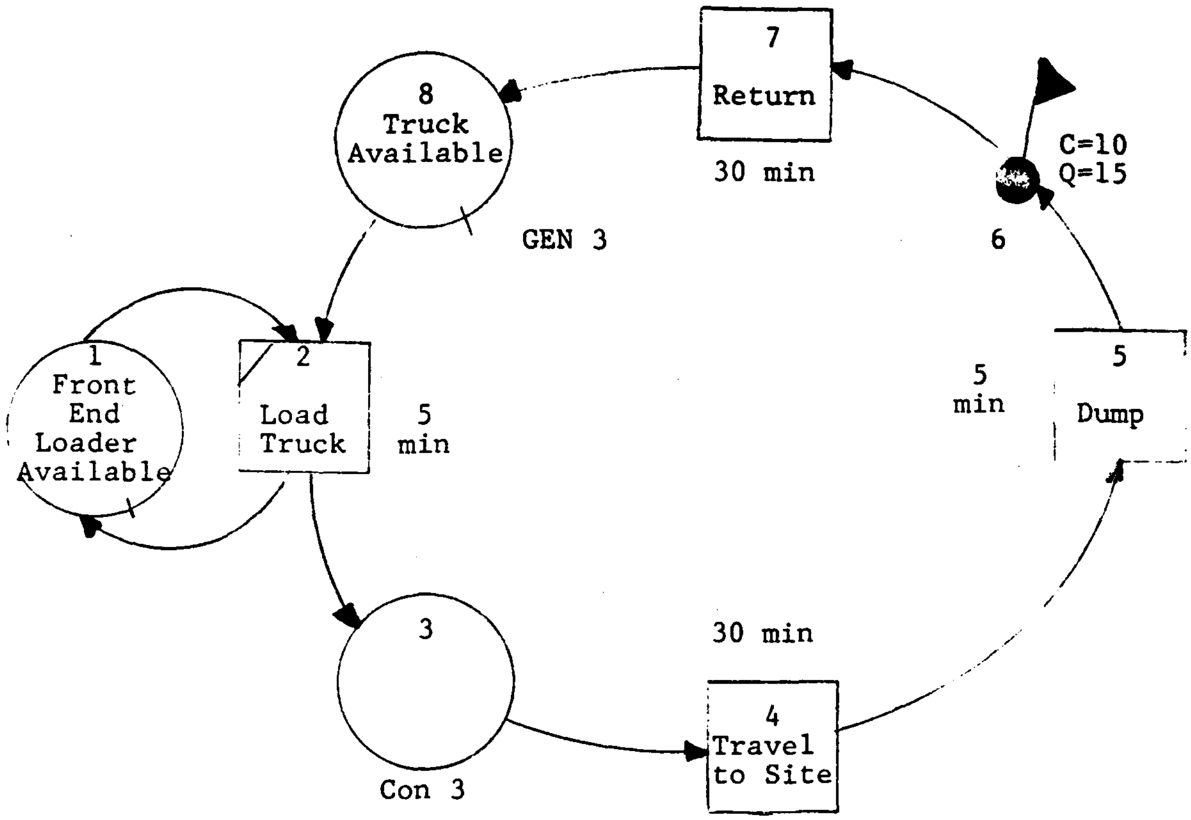
To employ the CYCLONE model, basic symbols are used to diagram the construction activity. These symbols are shown in Figure 1. The first element listed in Figure 1 is the NORMAL, which is similar to a COMBI, but different in that it processes resource units as they arrive and in the time associated with the NORMAL. In the earth hauling model of Figure 2, the NORMAL is represented by "TRAVEL TO SITE," "DUMP," and "RETURN," with times of thirty minutes, five minutes, and thirty minutes, respectively.

The next symbol listed is called a COMBI, which is a work task that is constrained by the fact that it must wait for two or more separate resources to arrive prior to it processing the work. In Figure 2, the COMBI is symbolized the activity "LOAD" since it cannot load the truck until a truck arrives, and the front end loader is available to load it. As shown, once the truck and front end loader are available, work commences and the truck is loaded or processed in five minutes. A COMBI is always preceded by two or more QUEUE nodes.

NAME	SYMBOL	INTRINSIC FUNCTIONS	DEFINED FUNCTIONS	REMARKS
NORMAL Work task		User-defined time delay	None	
Combination (COMBI) Processor		1. Ingredience constrained 2. User-defined time delay	None	
QUEUE Node		1. System-generated ingredience delay 2. Monitoring system generated ingredience delays 3. Entity initialization 4. Delay statistics	Entity generation Entity initialization Statistics (other) Marking	The GENERATE function associated with a QUEUE node is stipulated by the abbreviation GEN below the symbol
ARCS		Entity flow logic	Transit probability	
ACCUMULATOR (Counter)		Accumulation of system	Experiment Duration Control	
FUNCTION Node		None	Consolidation Statistics collection Marking Counting	The defined function associated is indicated by abbreviation CON-CONSOLIDATE STAT-STATISTICS MARK-MARKING KOUNT-COUNTING

Figure 1. CYCLONE System Modeling Elements.*

*Obtained from: Design of Construction and Process Operations by Daniel W. Halpin and Ronald W. Woodhead, NY, NY: John Wiley & Sons, 1976, p. 81.



Flow Unit = one 15 cy dump truck

Figure 2. CYCLONE Model for Earth Hauling Operation.*

*Obtained from: A CYCLONE Modeling Approach to the Fabrication and Installation of Prestressed Concrete Decks by Richard F. Haas, Jr., Master's Degree Special Research Problem, School of Civil Engineering, Georgia Institute of Technology, 1977, p. 9.

A QUEUE node is a collection point for resource units waiting to be processed. As such, it has no time duration assigned, but collects one type of resource unit and holds it until another type of resource unit is available for processing to commence. Another function of a QUEUE node is the GENERATE (GEN) function which increases the incoming resource unit by the GEN constant. Figure 2 includes a QUEUE, which is "FRONT END LOADER," and a QUEUE-GEN, which is labeled "TRUCK AVAIL." The model diagrammed in Figure 2 assumed a loader capacity of five cubic yards, and a truck capacity of fifteen cubic yards. Thus a single truck arriving at QUEUE-GEN 3 is converted into three load positions. Once the processing begins at the COMBI, the truck receives three loads from the front end loader.

The FUNCTION node is utilized to perform special functions such as consolidation, statistics collection, marking, or counting. It can be utilized anywhere in the model except between a COMBI and preceeding QUEUEs. The earth hauling model of Figure 2 shows a CONSOLIDATION (CON) function which is assigned a constant value, similar to a GEN function, for trapping the resource units as they flow out of the "LOAD" COMBI. The CON node holds the flow units until the number of units equals the value assigned to the CON node. In this case the CON node holds the truck until it receives three loads, the value assigned to the CON node, and then releases the three loads as a single truck.

The ARC is merely a symbol which indicates the path and direction of flow of the resource units as they move through the CYCLONE model. No time duration is assigned to an ARC.

The ACCUMULATOR is a monitoring device which is inserted into the CYCLONE model to count the flow units passing through the model. Once the ACCUMULATOR has counted the number of user-defined units, the CYCLONE model processing is shut down. A QUANTITY function is also associated with the ACCUMULATOR which multiplies the COUNTER by a user-specified constant. For example, in Figure 2, ten truck loads are specified (C=10), and each truck load is equal to fifteen cubic yards (Q=15). Therefore, the CYCLONE model would terminate after ten truck loads were dumped and calculate a total of one hundred and fifty cubic yards production for the system.

Productivity and the effective use of resources are monitored at QUEUE, FUNCTION, STATISTICS, and ACCUMULATOR nodes in a CYCLONE model.[65] In running a CYCLONE model, a hypothetical clock is turned on when resource units begin to flow through the model. As units move through COMBIs and NORMALs, time advances based on the assigned durations. Time continues to run as units wait in QUEUEs. Once the ACCUMULATOR has counted the desired number of units, the CYCLONE model is shut down and the time clock is stopped. A production rate can then be calculated from the compiled data. In the example presented in Figure 2, a production rate of cubic yards per hour can be calculated by knowing the total amount of time required to process one hundred and fifty cubic yards of earth.

Modeling of construction activities in the CYCLONE format is now possible on microcomputers and has been implemented on an Apple II Plus system produced by Apple Computer, Inc. and a TRS-80 Model I system made by Radio Shack, a division of Tandy Corporation.[66] Transformation of CYCLONE into a microcomputer format will allow modeling and analysis of construction activities at the job site which should further enhance productivity on the job.

Additional information regarding the CYCLONE modeling process can be obtained from Design of Construction and Process Operations by Daniel W. Halpin and Ronald W. Woodhead.

Segmental Bridge Construction

Segmental concrete bridge construction is a fairly recent evolution in bridge construction. Its use in the United States is even more recent, having first been utilized in Europe. The first matched cast segmental bridge with epoxy joints, the Choisey-le-Roi over the Seine River, which was completed in 1962, was designed by Jean Muller, who has designed bridges in France, America and other parts of the world.[67]

The use of precast segmental box girders incorporating prestressed concrete is the latest development for long span bridges.[68] Prior to the introduction of segmental box girder bridges, bridges utilizing prestressed concrete evolved from small simple span structures to major projects by using the techniques of drop-in spans, continuity, long girders, pre-tensioning, post-tensioning, precast beams, and cast-in-place girders.[69] Prestressed concrete is used in bridge construction for the following significant reasons:[70]

1. Economy
2. Durability
3. Fast construction
4. Low maintenance
5. Esthetics
6. Availability
7. Control of stresses

The aerial guideway for the Metropolitan Atlanta Rapid Transit Authority (MARTA) rail line near the Oakland City Station and near the Lenox Station is being built using precast post-tensioned segmental concrete construction. This construction technique involves erection of one span at a time on a moveable truss system which is placed between supporting cast-in-place concrete piers. The precast concrete segments are placed on the truss by a crane, pulled into position, and post-tensioned once all the segments are on the truss completing the span. This is almost identical to the erection procedure developed by Jean Muller and first used on a segmental concrete bridge as part of the Long Key Bridge project in the Florida Keys.[71]

The typical erection sequence[72] developed by Jean Muller for an interior span on the Long Key Bridge project is as follows:

1. Install the assembly truss between piers.
2. Position all segments in the span on the assembly truss.
3. Adjust deflection (alignment).
4. Place closure joint.
5. After curing of closure joint, stress tendons.
6. Release tendons at bottom chord of assembly truss and lower it so it can be moved to the next span.

It appears that the use of segmental concrete construction is on the rise in the United States, and one of the primary reasons is economics. On three bridge projects in the Florida Keys, the Long Key Bridge, the Seven Mile Bridge, and Channel No. 5, it was estimated that cost savings amounted to $12.6 million due to the use of segmental, post-tensioned concrete, box girder construction.[73] Encouraged by the lower cost of construction of segmental bridges over conventional construction, the Florida Department of Transportation is interested in determining the cutoff length at which segmental would be the practical choice over more conventional construction such as I-Beam and box beam stringer type bridges.[74] In a number of contract awards for birdge construction, where alternate construction methods have been available to contractors at the time of bidding, segmental construction has been the winner.[75]

The economy of segmental construction can be related to its speed and simplicity. It also lends itself to a number of construction techniques. By presenting a variety of methods, contractors can adjust the project to fit their resources (manpower and equipment) and thus maximize efficiency and optimize cost.[76]

Casting and erection of segments for bridge projects include the following fundamental concepts:[77]

<u>Precasting Techniques</u>. Match casting of segments involves casting segments in the same sequence as they will be erected, and is done by casting each one directly against the face of the previous segment using a debonding agent to prevent bonding of the concrete. The two most common methods for match casting segments are the short line system and the long line system. The short line system is the more common method used and produces about four segments per week per set of forms. An advantage of a short line system is the minimal space required for set-up. With this system, a segment is made, cured, moved out of the form, and the form set up for the next segment. The long line system is much the same except that a continuous soffit the length of a cantilever is built. The segments making up a span are cast in their correct relative position with the side forms moving down the line as each segment is cast. Advantages include

easy set up and control over a long line of segments as they are cast, and the strength of the concrete is not as critical since the segments are not immediately moved. Drawbacks involve the need for more space, a strong and settlement-free foundation, and curing and handling equipment which can move as the side forms travel along the soffit.

Erection Methods. The balanced cantilever method solves problems such as inaccessable terrain, existing traffic problems, and environmental restrictions. This "classic" technique requires the segments to be attached in an alternate manner at opposite ends of cantilevers supported by piers. Delivery of segments to the ends of the cantilevers is by various means. It is usually done by crane in the United States. Other delivery schemes involve launching gantries, which can lift a segment and deliver it to its position on the cantilever. A modified version of the balanced cantilever concept is the progressive placing method which erects cantilevers in only one direction by use of a crane which can lift a new segment delivered along the previously completed portion of the bridge and, pivoting around, lower the segment to be attached to the end of the cantilever. A third method, known as span by span erection, utilizes an assembly truss between permanent piers to support precast segments before they are installed and post-tensioned. A crane places the segments on the truss where they are assembled into a "span," post-tensioning tendons installed and stressed. Once the post-tensioning is completed, the truss is moved ahead to the next span by the crane.

It appears that the future of precast segmental concrete construction is unlimited. This is supported by Jean M. Muller, Chairman of the Board and Director of Research and Design for Figg and Muller Engineers, Inc., in the following observations:[78]

1. Most of the new bridges in the United States have sites suitable for segmental concrete design.

2. On the basis of concrete segmental bridges that have been built plus the construction and design experience which exists today, concrete spans in the order of 1,500 to 1,600 feet may be considered immediately feasible.

3. Further development will increase this limit.

4. The inherent advantages of concrete provide: (a) aerodynamic stability; (b) aesthetics; (c) low maintenance; and (d) lowest initial cost.

CHAPTER III

MARTA CONSTRUCTION

The rapid transit system for Atlanta, Georgia, as envisioned, totals more than 50 miles of rapid rail service and is being constructed under the guidance of the Metropolitan Atlanta Rapid Transit Authority. The rail system consists of underground, on-grade, and elevated sections along various routes. Figure 3 provides a plan view of the entire MARTA rapid transit system.

Two areas which are receiving elevated rail lines are located on the South Line near the Oakland City Station, and on the North Line near Lenox. Contract CS-360 Earthwork and Structures, White Street to Evans Crossing and Contract CN-480 Earthwork and Structures, Canterbury Road to East Paces Ferry Road, include the aerial guideway construction for the Oakland City (5230 LF) and Lenox (1880 LF) areas, respectively.

The contractor for both projects is J. Rich Steers, Inc. The work is being administered by Parsons, Brinckerhoff, Quade and Douglas, Inc. and Tudor Engineering Company, otherwise known as PB/T, which has a contract with MARTA for construction management and inspection of MARTA projects.

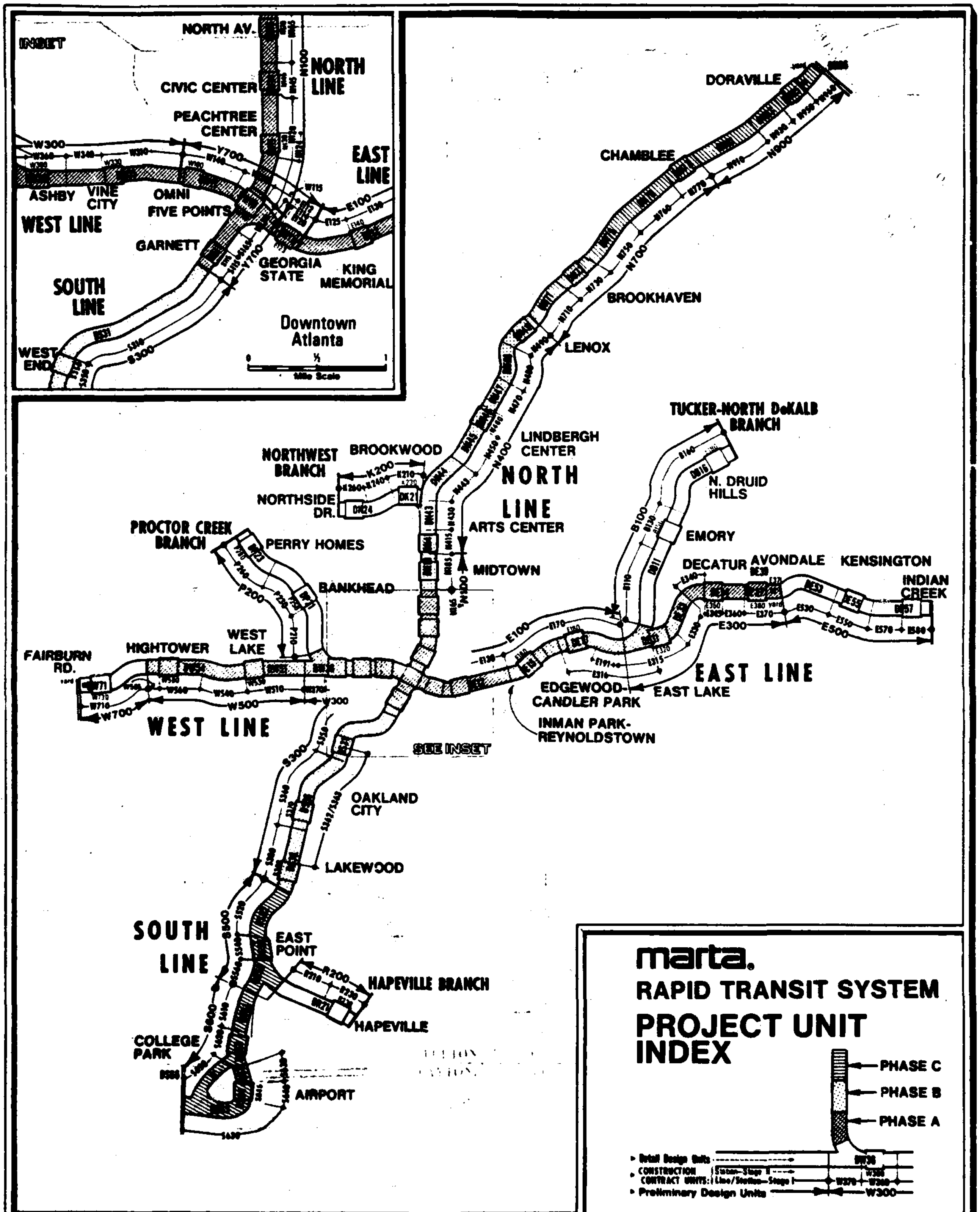


Figure 3. MARTA Rapid Transit System.

The elevated guideway for the rail line is being constructed at the locations mentioned above by utilizing precast post-tensioned segmental concrete construction. The erection procedure is nearly identical to that developed by Jean Muller and used in bridge construction in the Florida Keys. In fact, the services of Figg and Muller Engineers, Inc. were used by J. Rich Steers, Inc. to design the segmental spans for these two contracts. Figure 4 provides an indication of the erection procedure, while a description is as follows.[79]

The girder and deck, called the superstructure, is composed of spans ranging from 70 to 100 feet on the Oakland City site and up to 140 feet on the Lenox site. Each span is made up of a series of precast segments which are cast in a yard located on the site of the future Oakland City Station parking lot. A typical span has a varying number of 10' segments, two variable length segments, and a standard pier segment for each of the two piers supporting the span. The segments are of a trapezoidal shape with a constant depth of 7' and an outside measurement of just over 30' across. Figures 5 and 6 show a cross sectional view of a typical 10' segment and pier segment, respectively.

The span, or superstructure, is erected utilizing the span-by-method of erection. This involves using two erection trusses which were designed and built for these projects. Figure 7 shows the trusses being positioned between two piers. The trusses are supported between two piers by support brackets

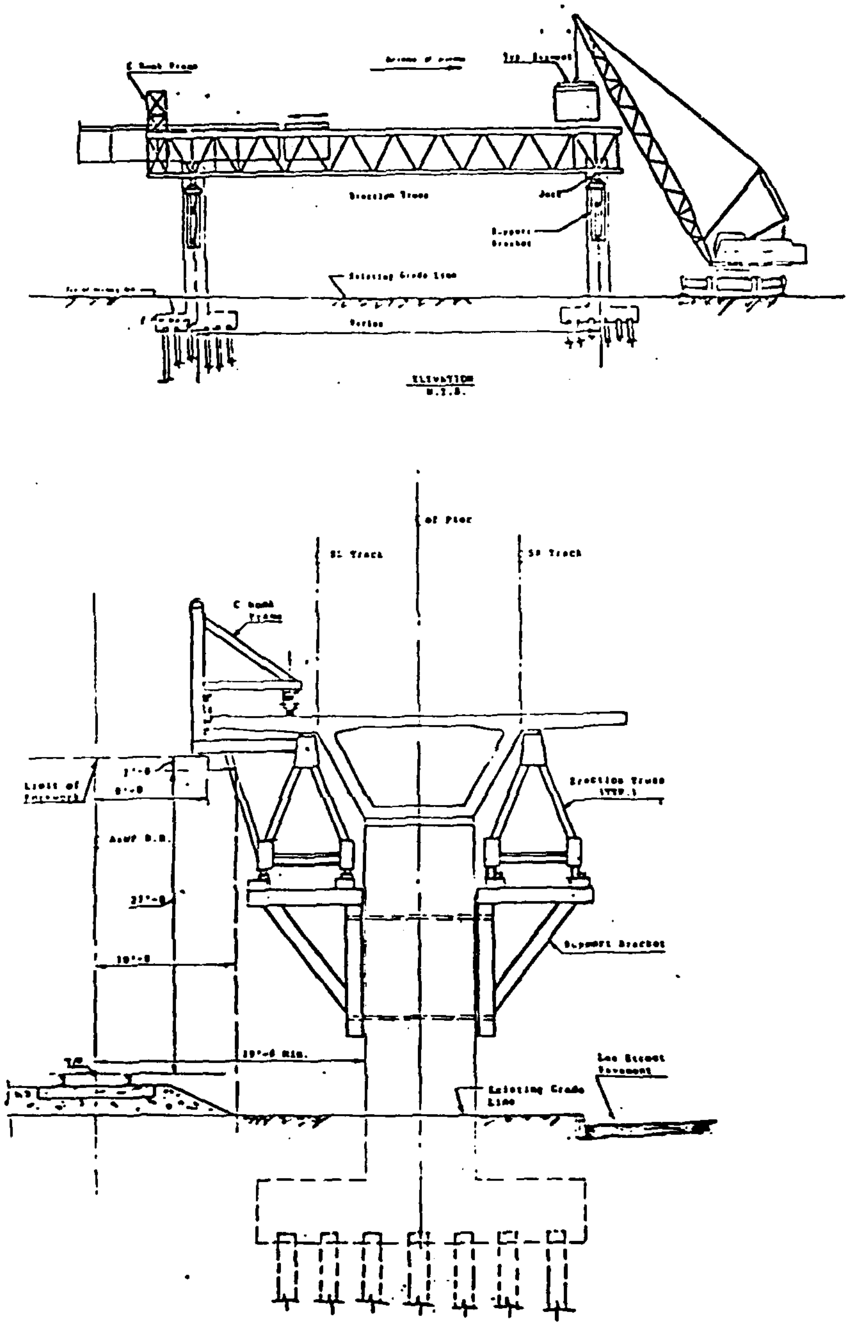


Figure 4. Erection of Precast Segments on Span.

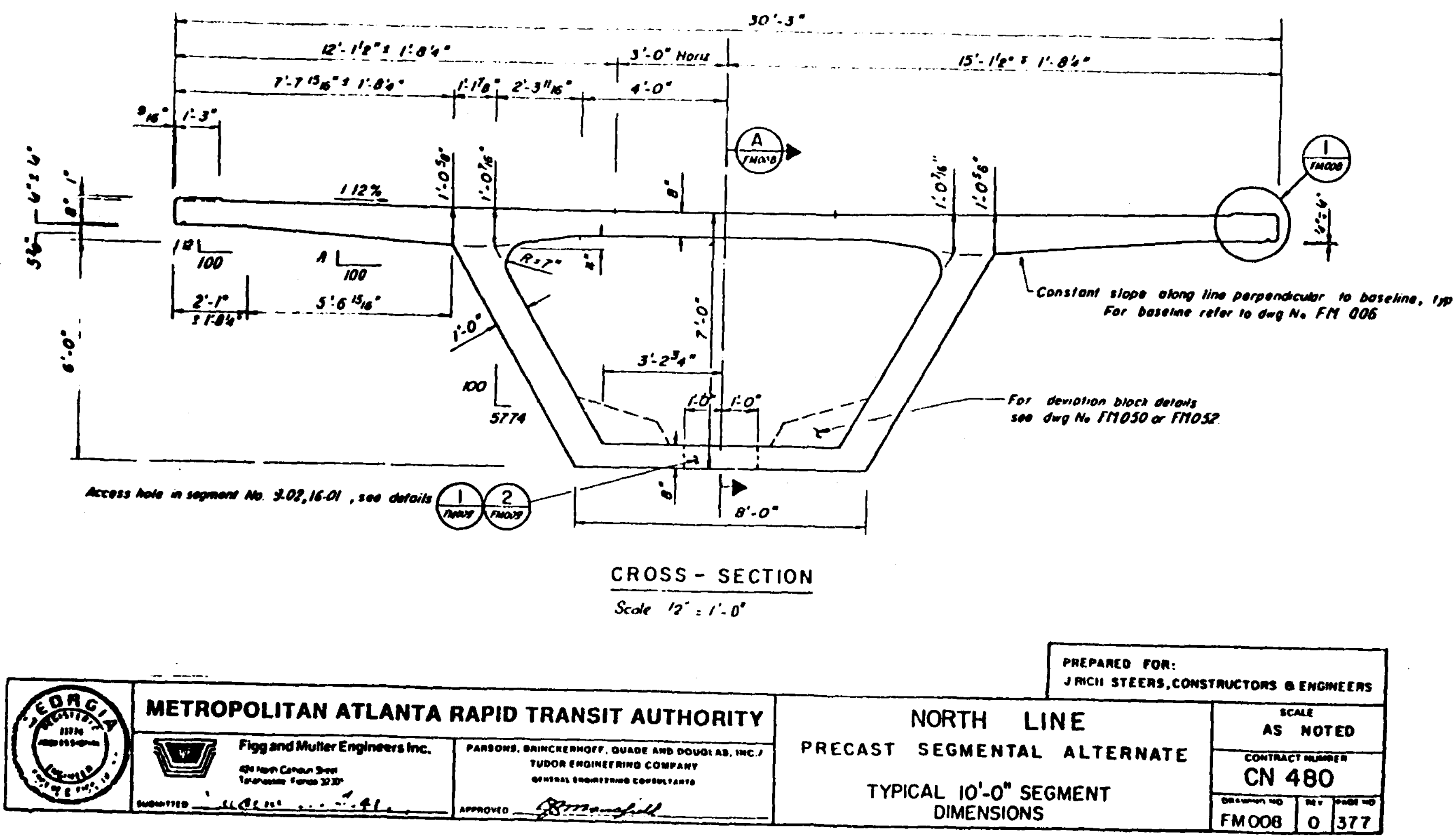


Figure 5. Typical 10' Segment (Cross Section).

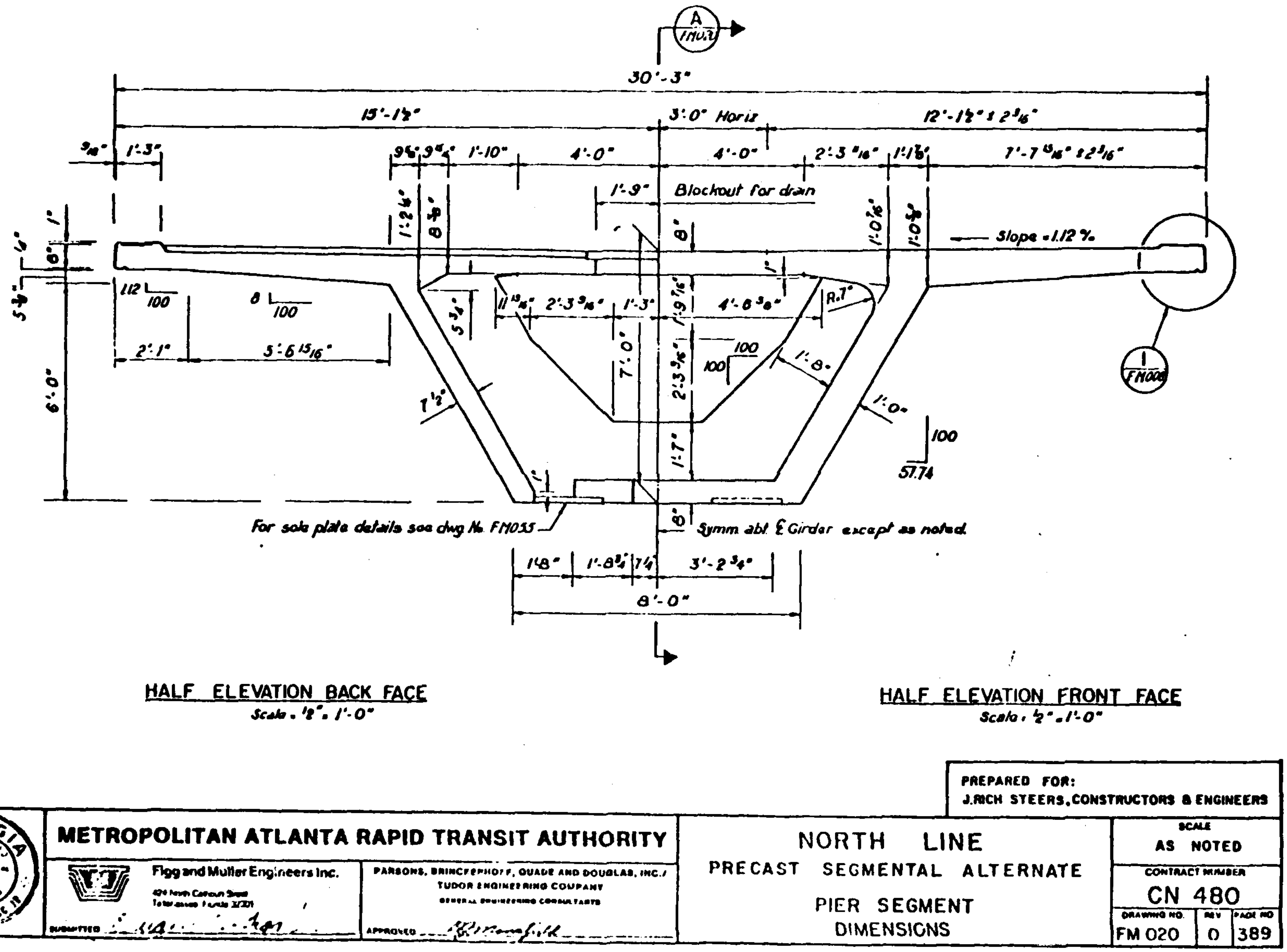


Figure 6. Typical Pier Segment (Cross Section).

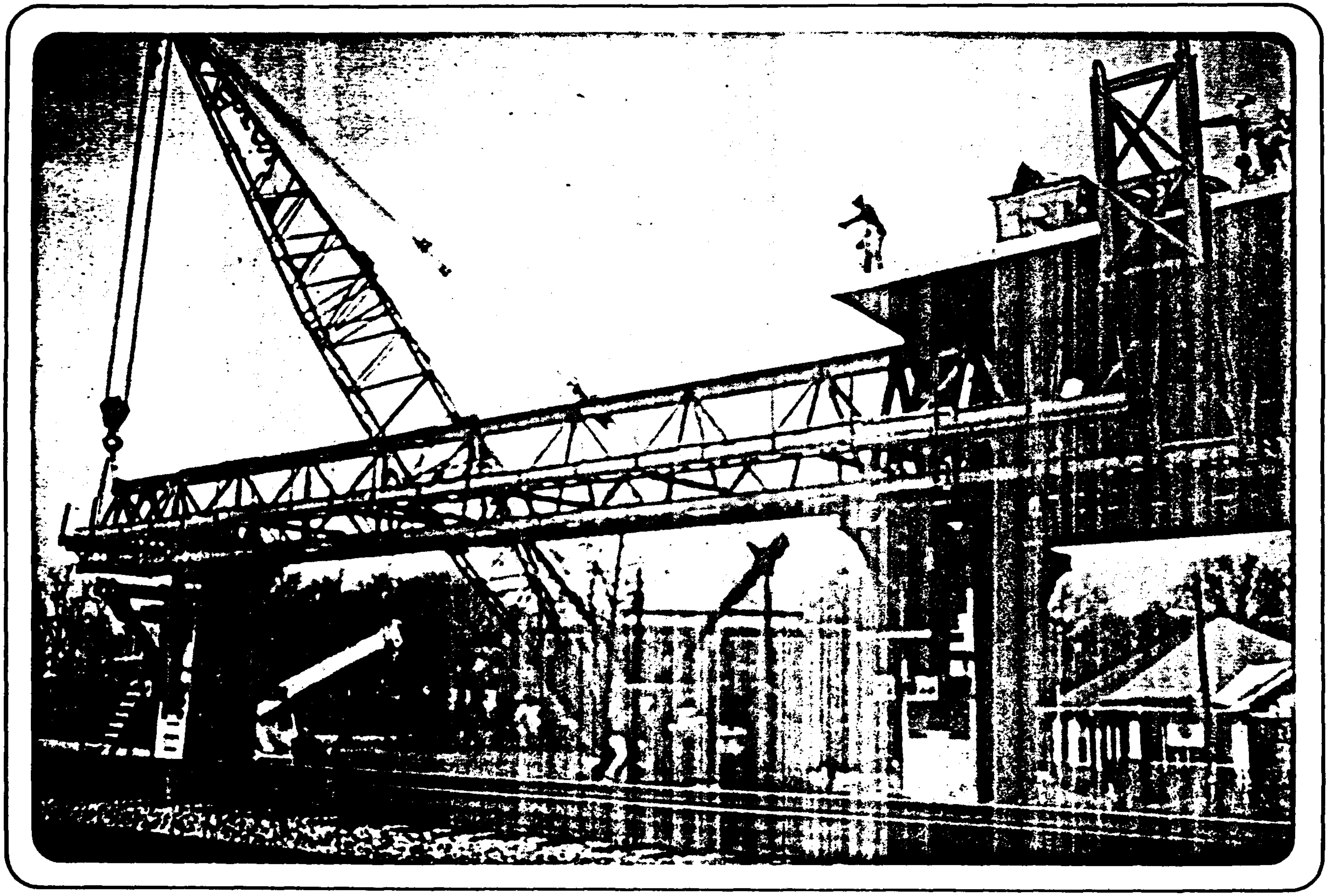


Figure 7. Trusses Being Positioned Between Piers.

which are temporarily attached to the pier. There are three sets of brackets so that while two are in use supporting the trusses, the third is being relocated in preparation for moving the trusses. Figure 8 shows a bracket attached to a pier prior to the trusses being positioned. The precast segments are lifted onto the trusses by crane (see Figure 9) and rolled into place to form the span. Figure 10 shows the rollers which support the movement of the segments along the trusses. Once all the segments are in place and aligned (see Figure 11 for picture of hand-operated hydraulic jacks which are used to level and align the segments), the PVC conduit is installed and the cable strands are threaded through the PVC conduit and post-tensioned. Figures 12 and 13 show the post-tensioning operation. The span is then lowered into place on the piers and the trusses moved forward to the next pier where the process is repeated for the next span. The PVC conduit containing the strands is filled with grout by pumping the grout into the conduit under pressure. This is done after the span has been lowered onto the piers and the erection procedure moved forward.

This method of construction (precast segmental construction) has proved valuable in reducing construction time and construction costs. Although first used in Europe, segmental construction is enjoying increased use in the United States.

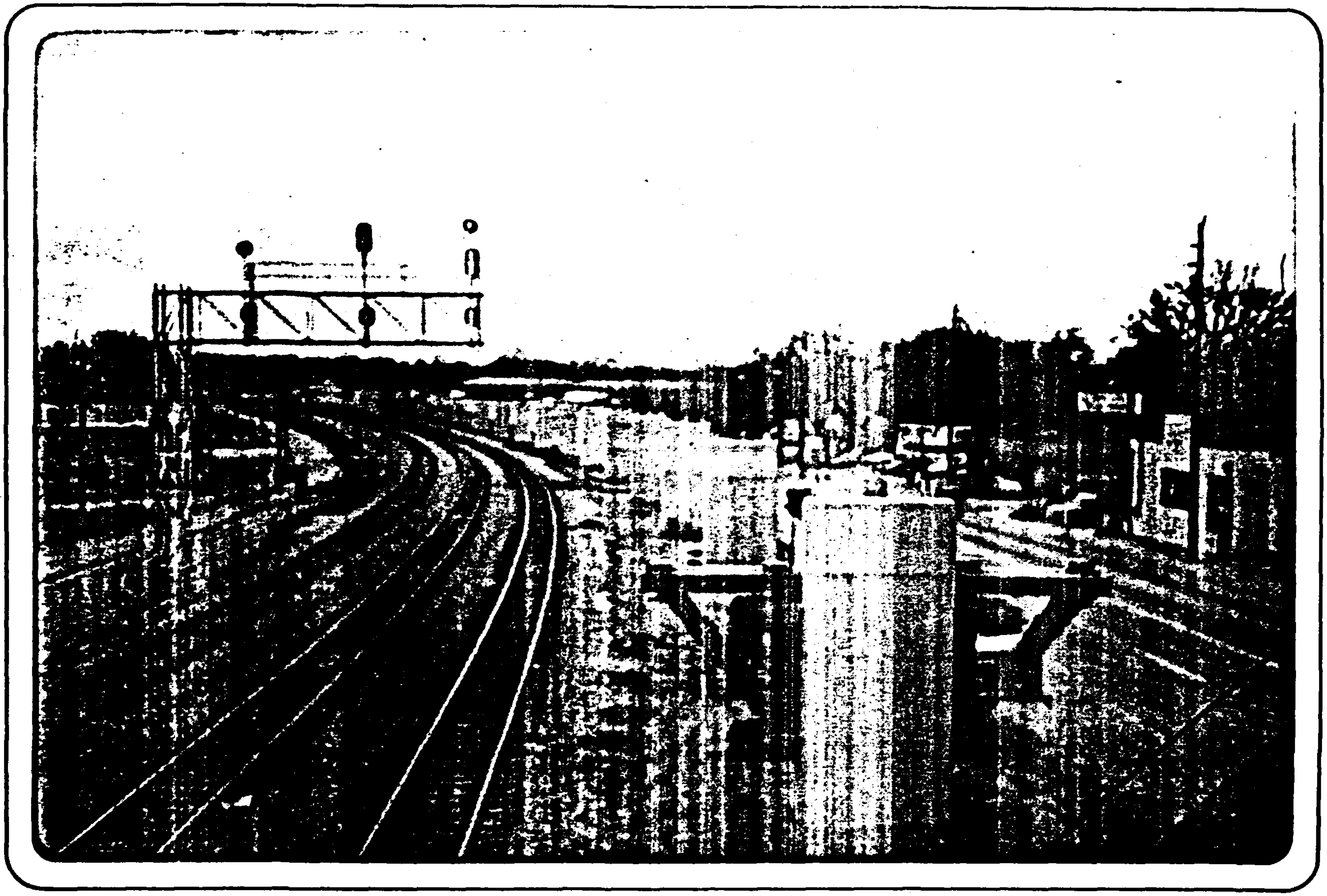


Figure 8. Brackets Attached to Pier.

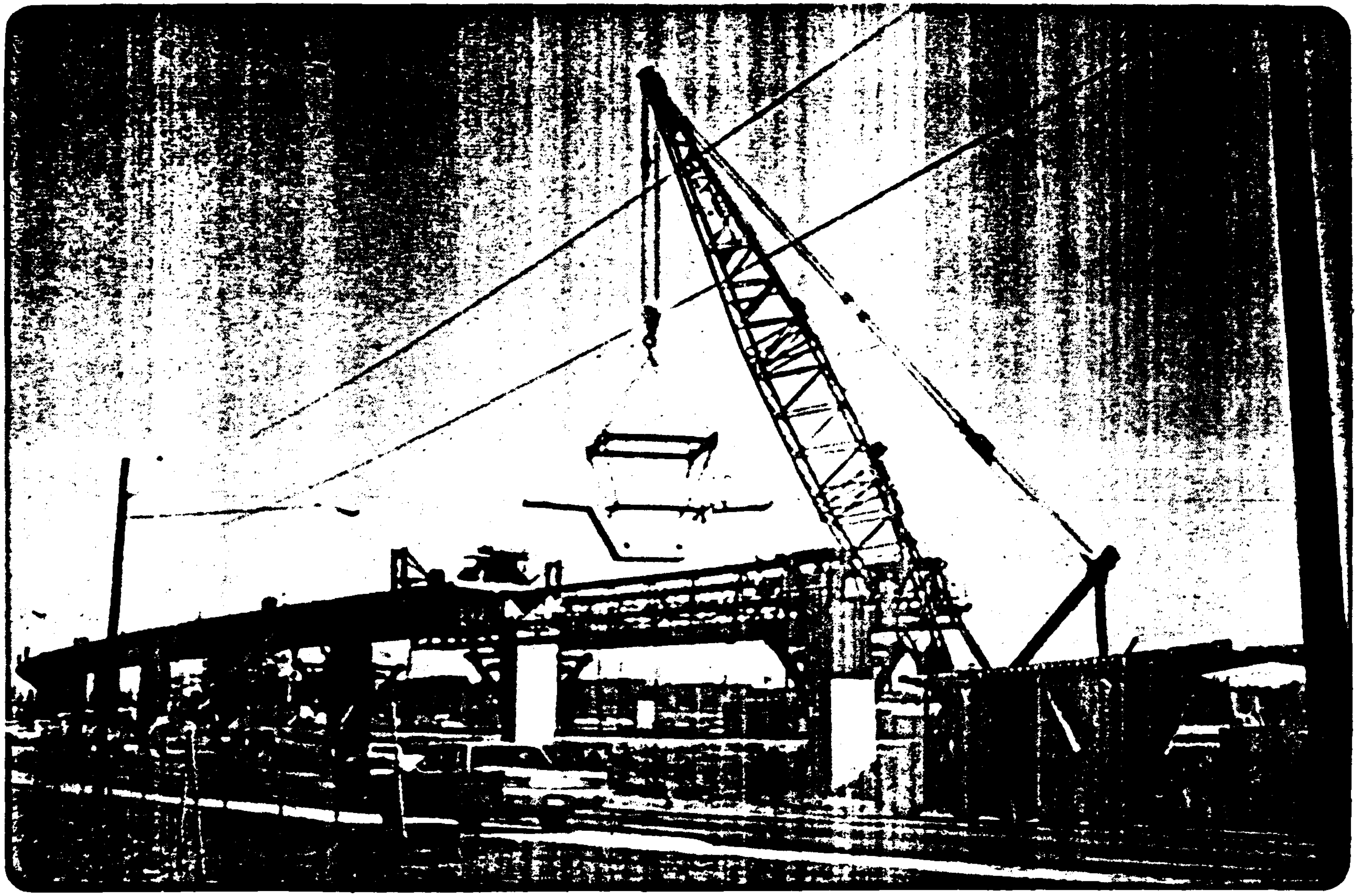


Figure 9. Segment Being Loaded on Trusses.

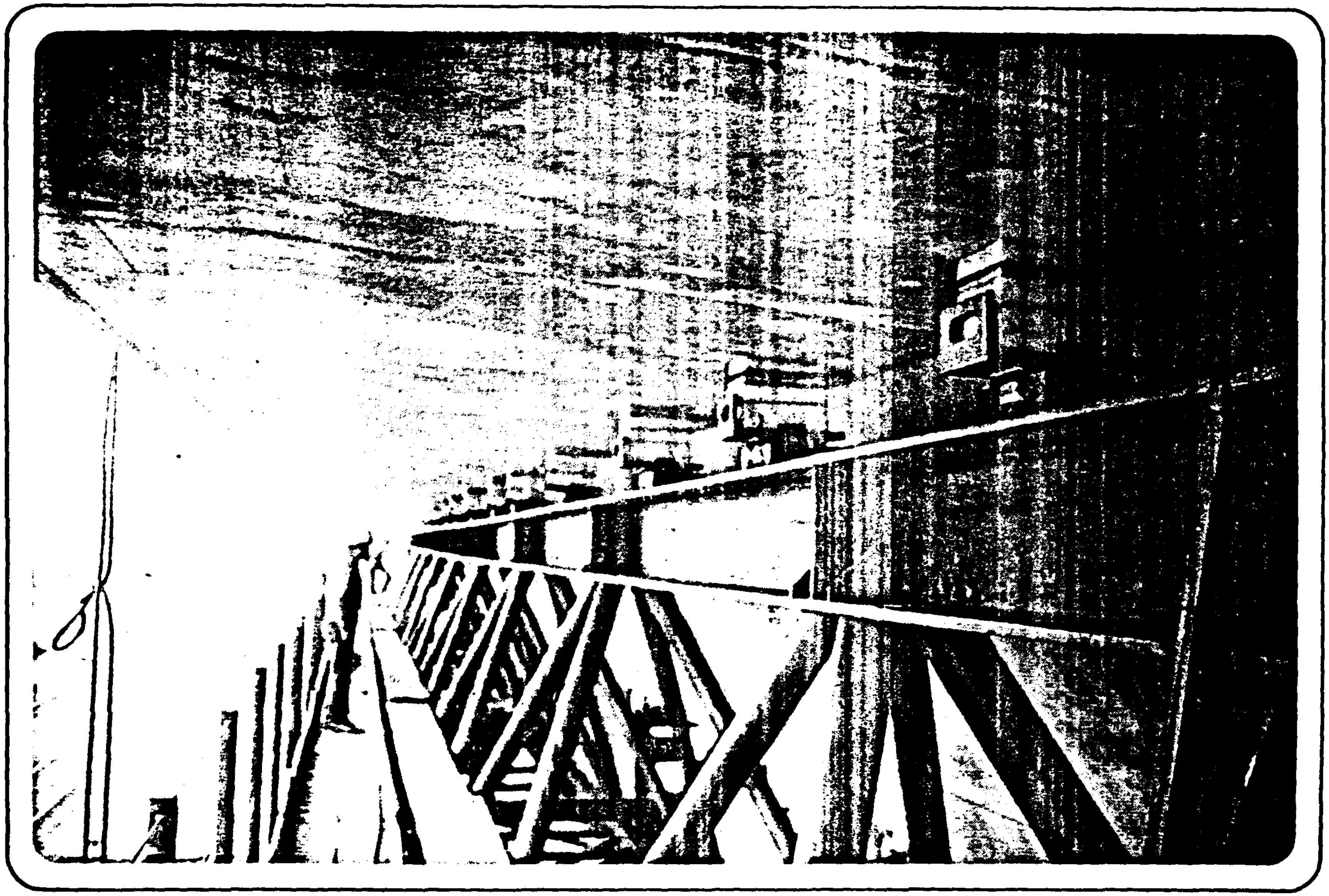


Figure 10. Rollers Supporting Segments on Truss.

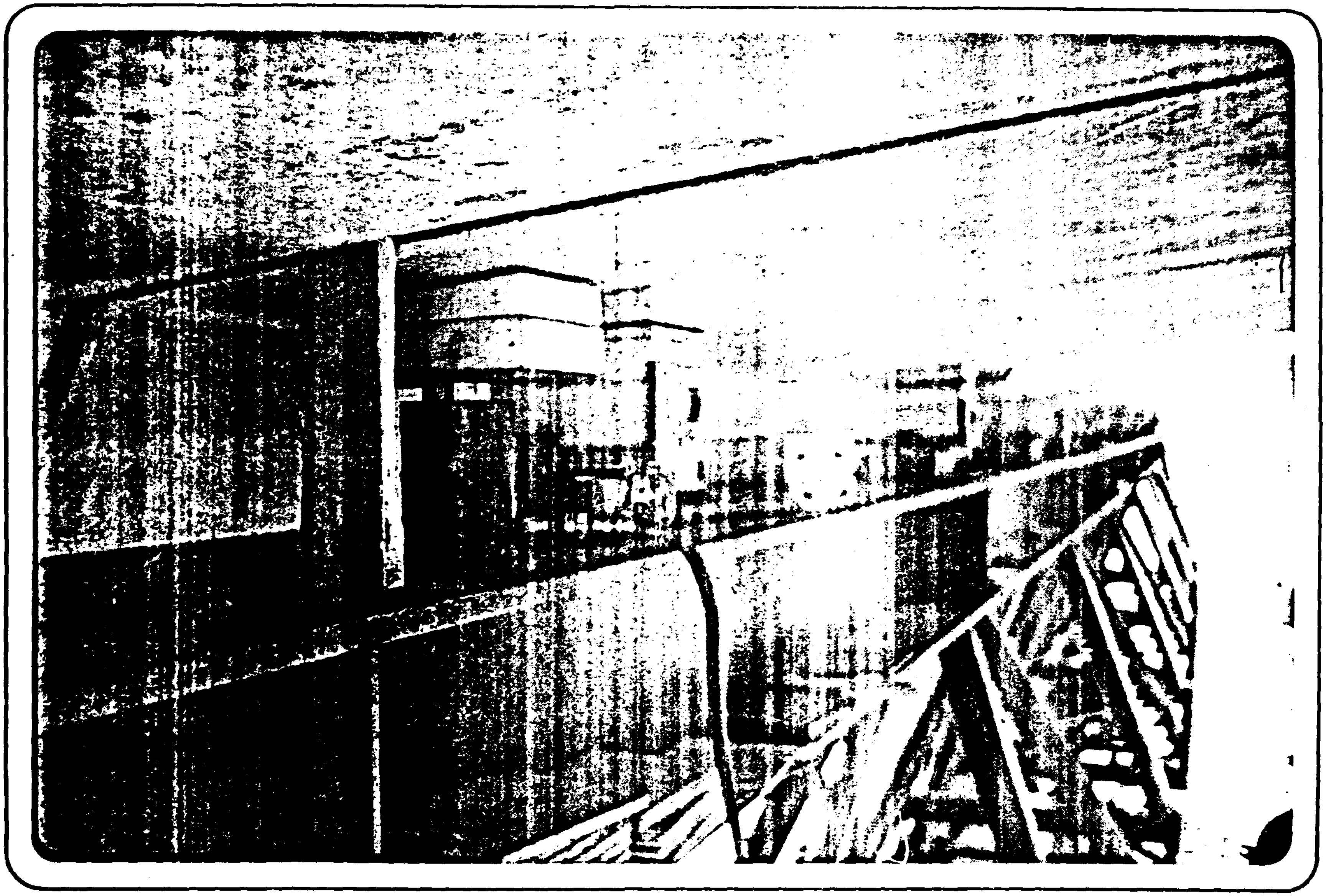


Figure 11. Hydraulic Jack Used for Alignment of Segments.

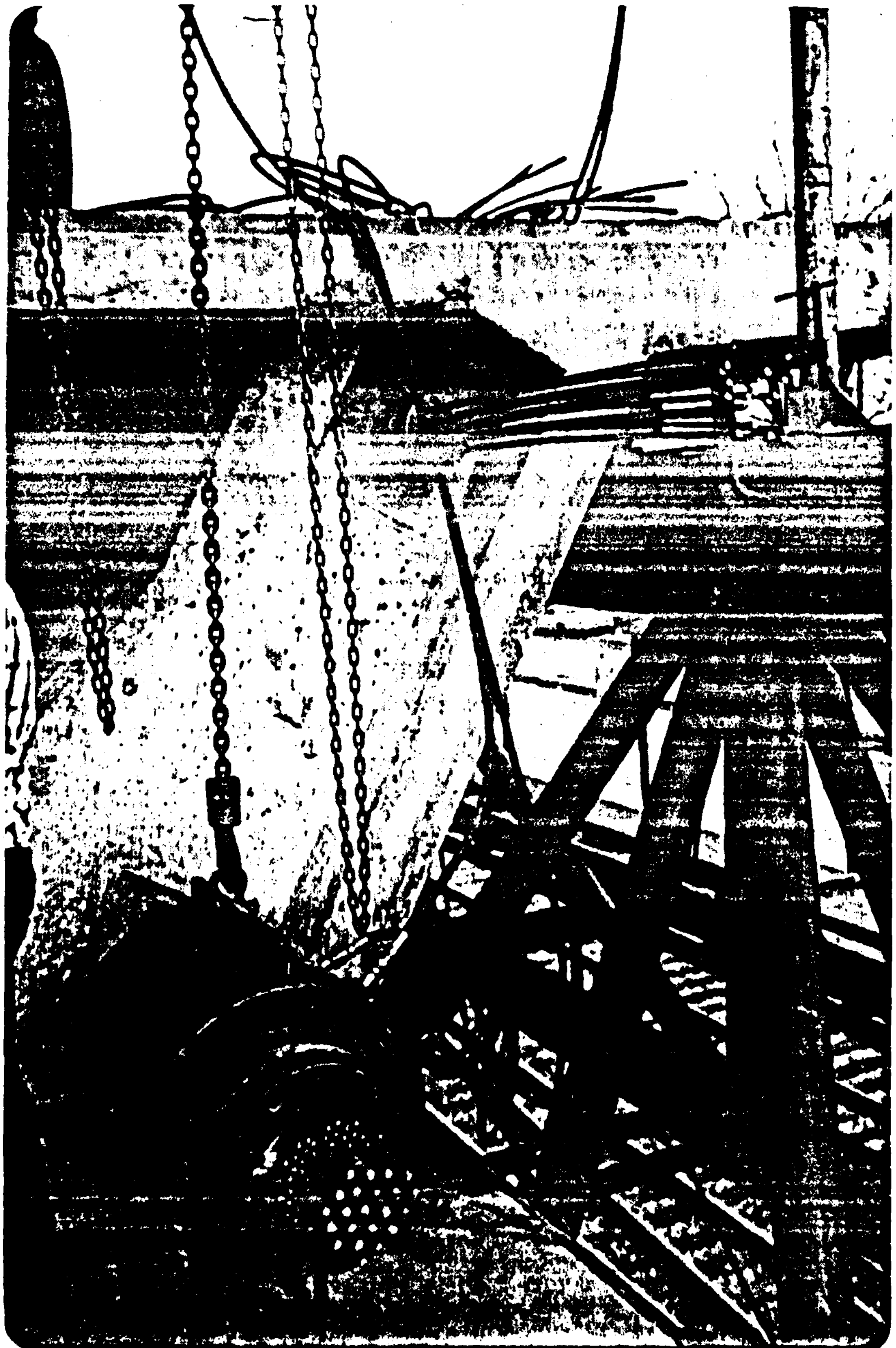


Figure 12. Post-Tensioning Jack in Place.

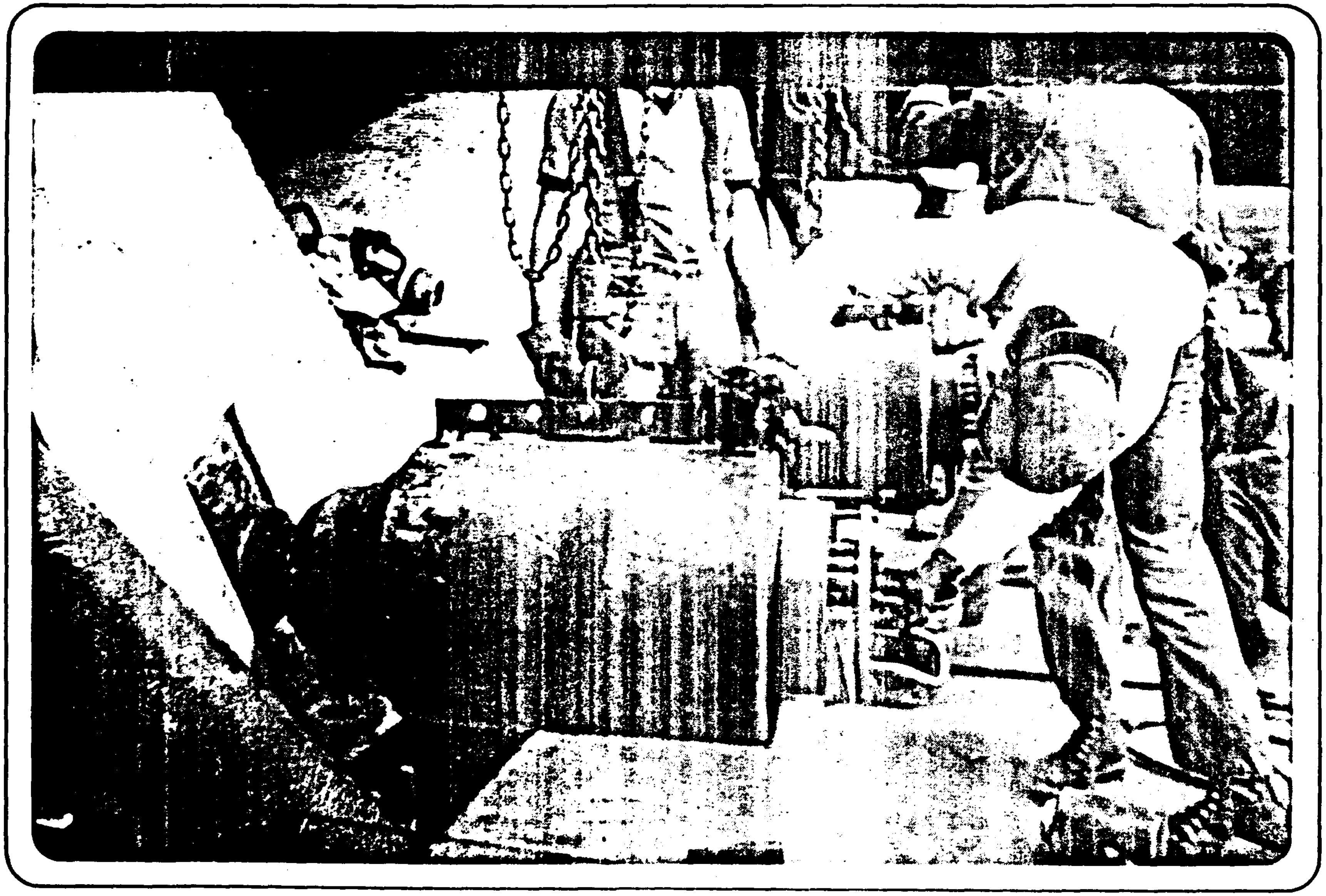


Figure 13. Crew Preparing for Post-Tensioning of Lower Strands.

CHAPTER IV

MODEL FORMULATION AND METHODOLOGY

Field Data

One of the purposes of this paper is to obtain duration times for work activities in the field by use of stopwatch studies and time-lapse films in order to compare the two methods as to advantages and disadvantages of each. This was done on two MARTA rail line contracts for precast segmental aerial construction of the elevated guideways near the Oakland City Station and the Lenox Station.

Stopwatch studies were conducted using a digital watch to record the time an activity started and stopped. An actual stopwatch, which can be reset to zero after timing each activity, was not used. The method used with the digital watch is similar to the Continuous Timing technique described by Mundel and outlined in Chapter II in which actual times are recorded and durations for activities obtained later by successive subtractions of the recorded times. This method proved useful as there were activities which began before previously started activities had completed. Thus, by recording the start and finish times of activities, durations were obtained without resorting to the use of several stopwatches.

Timelapse films were made of the erection process at both the Oakland City Station and Lenox sites. A Minolta Autopak 8D10 Super-8 movie camera and tripod belonging to the Georgia Institute of Technology was used to film the work. The movie camera was equipped with an intervolometer which allowed the camera to be used to take time-lapse films. The intervolometer trips the camera shutter automatically at preset time intervals. The intervolometer allowed exposure rates of one frame every 0.5, 1.0, 2.0, 4.0, 8.0, 15.0, 30.0, and 60.0 seconds. For the filming at the project sites the camera was set up to take one frame every four seconds. This equates to 15 frames per minute and when viewed at a speed of two frames per second on a special projector, allows an eight-hour work day to be viewed in one hour.

In obtaining field data, the stopwatch studies were conducted separately and, at other times concurrently, with the time-lapse filming. Since the time-lapse camera and attachments are expensive pieces of equipment, they were not left unattended in the field. Although the ability of a time-lapse camera to remain unattended while filming is one of its advantages, this was not done.

The construction site near the Oakland City Station proved to be less congested than the Lenox site even though it ran parallel to Lee Street and traffic lanes had to be blocked off in order to place segments on the trusses. The Lenox construction site ran parallel to the Southern Railway tracks but was located along a narrow right-of-way in a wooded area. The project site at Lenox also had only one access road and other major construction, such as placing concrete for the piers, in process while the erection of the segmental spans was underway.

Filming was done at the Oakland City and Lenox sites but only one film was obtained at each site. The film of the work on the south line near Oakland City included moving the trusses and placing the segments on the trusses. It covered a period of five hours including lunch break at which time the camera was turned off. The film of the work on the north line project also covered a five-hour period. There was not as much activity during the filming on the north line, although the trusses were moved, only one segment out of ten was placed. The north line film covered the period of time from 7:30 a.m. to 12:00 noon. It started raining at 1:00 p.m. and no further filming was possible that day. The film of the south line construction covered the period of time from 10:50 a.m. until 3:50 p.m. with a half hour off for lunch.

Difficulties in obtaining time-lapse films and recording durations of activities by the use of stopwatch studies can be attributed to the inability to effectively coordinate the erection process with the writer's class schedule and the weather. Rainy days brought the erection of the spans to a halt and on other days only certain activities were in progress such as post-tensioning or relocating brackets when the sites were visited between classes. Another problem with the filming operation and also in some instances with the stopwatch studies, was not being able to observe when some activities actually began and finished. For example, in the case of the stopwatch studies, the PVC conduit installation was not easily observed due to the work taking place inside the segments after they were placed on the trusses. The time-lapse camera had to be placed in a location so as to record on film as much of the erection process as possible. This was difficult at both sites and especially so at Lenox. For example, the dismantling, relocation, and installation of the brackets from one pier to another was not recorded on film since that activity was out of the view of the camera coverage. Also, the distance of the camera from the work in progress on the trusses and spans prevented the film from capturing exactly when certain activities began and ended. The detail required in filming the erection of precast segments for activity durations for the CYCLONE model was difficult if not impossible to accurately obtain.

After a few site visits and attempts in obtaining time data for field activities, it became apparent that a structured procedure was necessary in order to record activity durations. The following is a list of steps to follow when observing a multi-activity construction site to gather time data for CYCLONE input:

1. Familiarize yourself with the work by visiting the site and recording the activity.

2. Develop a CYCLONE model and check its validity with the Project Superintendent or someone familiar with the work.

3. From the CYCLONE model, determine what activities you want to analyze and condense or reduce your CYCLONE model as necessary to fit your needs.

4. Return to the construction site to obtain activity durations as outlined in your CYCLONE model.

CYCLONE Model Formulation

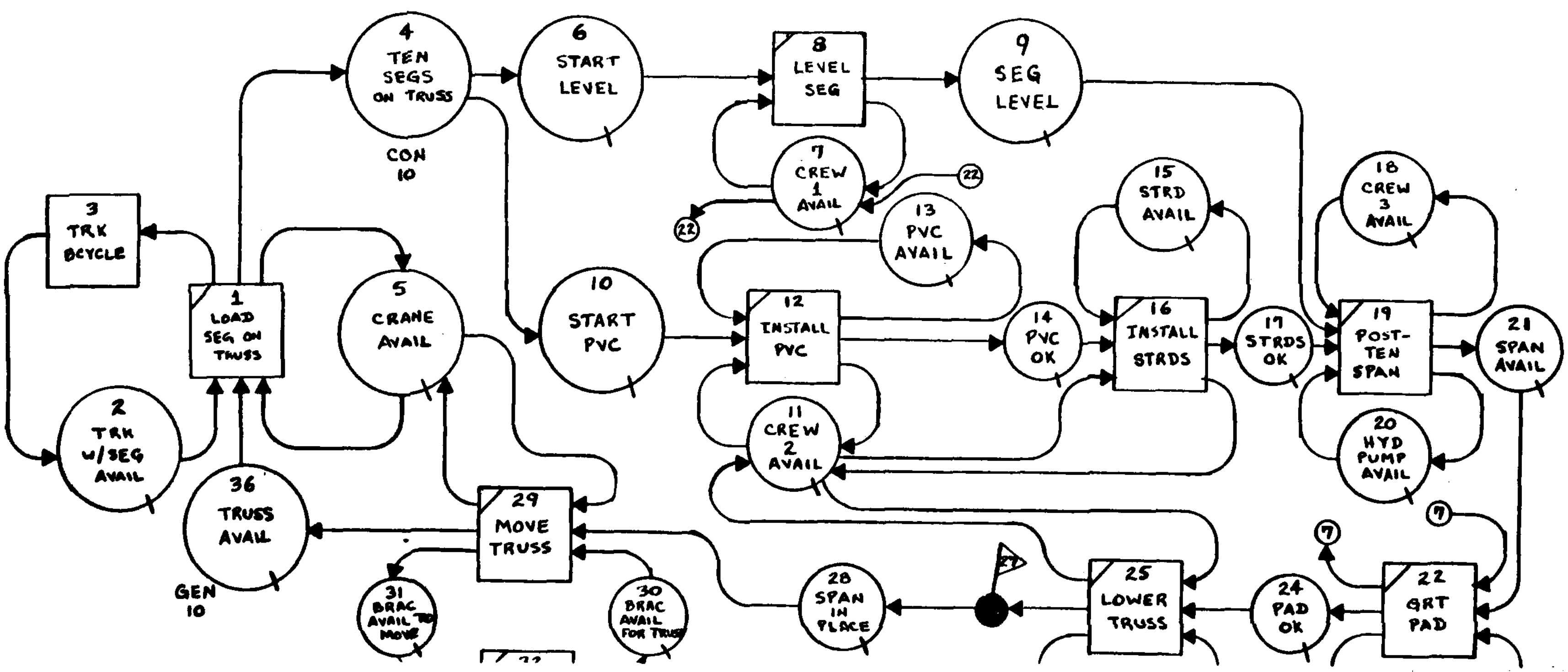
The CYCLONE model of the erection of precast post-tensioned segmental spans is shown in Figure 14. This model was developed from site visits and from viewing the time-lapse films of the erection operation. The level of detail in the model could be expanded or reduced according to the desires of the person analyzing the process of segmental construction.

The model portrays the installation of one span of the elevated guideway being constructed on existing cast-in-place concrete piers. In formulating the model, the following assumptions were made:

1. All materials (PVC, cable strands, grout, etc.) would be available when required.

2. All equipment (hydraulic jacks, cranes, etc.) would be available when required.

3. All crews would be available when required.



1 LOAD SEG ON TRUSS
2 TRK w/SEG AVAIL
3 TRK BCYCLE
4 TEN SEGS ON TRUSS
CON 10
5 CRANE AVAIL
6 START LEVEL
7 CREW 1 AVAIL
8 LEVEL SEG
9 SEG LEVEL
10 START PVC
11 CREW 2 AVAIL
12 INSTALL PVC
13 PVC AVAIL
14 PVC OK
15 STRD AVAIL
16 INSTALL STRDS
17 STRDS OK
18 CREW 3 AVAIL
19 POST-TEN SPAN
20 HYD PUMP AVAIL
21 SPAN AVAIL
22 GRT PAD
24 PAD OK
25 LOWER TRUSS
28 SPAN IN PLACE
29 MOVE TRUSS
30 BRAC AVAIL FOR TRUSS
31 BRAC AVAIL TO MOVE
36 TRUSS AVAIL
GEN 10

4. No delays would be encountered due to inclement weather, traffic conditions, or work site congestion.

5. All spans would receive 10 segments, although in actuality, this varied from 9 to 16 segments depending on the distance between piers.

6. Final grouting of the strands inside the PVC was not considered part of the erection process.

The flow unit through the model is one span which is composed of ten segments delivered one at a time by truck. The segments are placed on a truss which has been divided into ten sections by the GENERATE (GEN 10) node. The segments are formed into a span by the CONSOLIDATE (CON 10) node prior to cycling through the model. Once the span is formed, activity commences on leveling the segments, installing PVC conduit which will house the cable strands, and installation of the strands. At the completion of strand installation, the post-tensioning of the strands begins. As that is completed the bearing pads are placed and grouted on the piers and then the trusses are lowered completing the installation of one span and freeing the trusses for use on the next span.

While the span is moving through the model, the brackets which are used to support the trusses are "leap-frogged" to the next available pier so that as the trusses are moved forward a set of brackets becomes available for relocation to the next available pier. There are three sets of brackets. At any one time, two sets are in use supporting the trusses, while the other is being relocated to the next pier to receive the trusses.

The recording of activity durations in the field for use in the CYCLONE model through the use of stopwatch studies and time-lapse photography proved to be feasible. However, due to time constraints caused by weather, construction delays, and class schedules, it is not believed that adequate activity durations for the various CYCLONE activities were obtained from the field data. Therefore, estimated activity durations for the COMBINATION (COMBI) and NORMAL nodes are used for the simulation of the erection process. The estimated times were obtained from Mr. Rafik Elias, Field Engineer for Parsons, Brinckerhoff, Quade and Douglas, Inc./Tudor Engineering Company (PB/T), who is responsible for the segmental aerial construction. This time data was used in the computer input for the CYCLONE model "SEGMENT" which is listed in Appendix A.

The CYCLONE model data was input into the MICROCYCLONE program on an Apple II Plus System. The MICROCYCLONE program was copyrighted by Dr. Daniel W. Halpin in 1982. The use of a microcomputer for executing the CYCLONE model proved to be a much easier procedure than using a main frame computer which was done previously by this writer on a separate project.

Based on the estimated activity durations obtained from PB/T and the CYCLONE model developed from site visits and viewing time-lapse films, the MICROCYCLONE provided a production of 0.0299 spans per hour. Based on an eight-hour work day, this equates to 0.239 spans per day. Information obtained on actual spans erected during the period 12 November 1982 through 18 February 1983 indicates that 43 spans were erected during this period. Assuming there were 67 work days during this period, this equates to 0.642 spans per day. The 67 work days allow for some holiday time at Christmas and Thanksgiving but no lost time for inclement weather, etc. The large difference in production rates is to be expected since the CYCLONE times are only based on estimates, and there are other factors which have an effect on the production rates which are not considered.

Generally, the production rate generated by the MICROCYCLONE program is greater than the production rate obtained in the field. This can occur since actual delays on the job site do not appear in the CYCLONE modeling process. In this case, the field production rate was calculated to be 0.642 spans per day based on the following:

$$(43 \text{ spans}) \div (67 \text{ work days}) = 0.642 \text{ spans/day}$$

This calculated field production rate is greater than the 0.239 spans per day generated by the MICROCYCLONE program. Appendices B and C are printouts of the MICROCYCLONE "Production By Cycle" and "Process Report," respectively.

The fact that the field production rate is higher than the MICROCYCLONE generated production rate does not mean that the computer-generated reports are in error. The difference in production rates is to be expected since the CYCLONE activity times are based on estimates, not on actual field data collected from the stopwatch and time-lapse studies. Thus, in an attempt to estimate activity times, a tendency to exaggerate the actual time to insure that the activity duration was not estimated as less than actual, would cause the CYCLONE model to generate production rates less than those obtained in the field. Another factor is that the CYCLONE model assumes that each span requires 10 segments, while in actuality, many of the spans erected during the initial 67 work days required only 9 segments per span. Consequently, since there were many assumptions made in modeling the precast segmental construction, the difference in production rates is not considered alarming. The computer generated productivity could be increased by closer analysis of the span erection in order to obtain more accurate time data for the CYCLONE model active states.

The usefulness of CYCLONE modeling on the microcomputer is its availability for field use and the ease in which changes can be made to various parameters and constraints of the system being analyzed. This allows a project manager, field superintendent, etc. the ability to check on productivity and attempt various methods of improving productivity without actually having to perform the changes in the field.

As previously mentioned, adequate activity durations for the active states of the CYCLONE model were not obtained from the field data. Appendices D and E are facsimilies of the field data collected using the stopwatch method at the South Line and North Line construction sites, respectively. The two time-lapse films of the work were turned over to Dr. Daniel W. Halpin, School of Civil Engineering, Construction Management Program, Georgia Institute of Technology, Atlanta, Georgia.

As can be seen in Appendices D and E, there were many activities in progress during the erection of the spans. As it turned out, many of the activities recorded can be considered sub-activities of the active states listed in the CYCLONE model of segmental construction (Figure 14). The recording of actual durations for the active states in the CYCLONE model by the use of stopwatch studies proved difficult due to several factors. A major factor was the total amount of time required to erect one span in accordance with the CYCLONE model. If all work went smoothly, it was possible to almost complete one span in one work day; however, this would involve having the trusses in place ready to accept segments at the beginning of the work day. Another factor was the erection of a single span normally covered more than one day, thus it was difficult to obtain start and finish times for certain active states unless one was at the job site on consecutive days. This proved to be unworkable for the writer due to class schedules. A third factor which hindered collection of time durations was being able to observe all the activity on the job from a single vantage point. This was difficult for the span erection since the work involved overhead construction, which obstructed the view of the observer on the ground. In addition, the installation of the PVC conduit took place inside the segments after they were placed on the trusses. From ground level one could only estimate when work commenced and ended on the installation of the PVC. The post-tensioning of the spans was partially hidden from view when observed from ground level, thus accurate time data for this activity was difficult to obtain.

The use of time-lapse photography to record activities for further study to extract time data for activities proved to be unworkable with the equipment available. The Kodak Ektagraphic MFS-8 movie projector, which belongs to the Georgia Institute of Technology, was used to view the time-lapse films of the span erection. The projector has a slow motion setting for viewing films, but it proved to be less than satisfactory for obtaining activity durations from time-lapse films. There is no frame counter on the projector, thus making it practically impossible to count the number of frames of film rolling past on the screen. Without a frame count of the active states captured on film, it was impossible to convert the filmed activity durations to actual durations. The need for a specialized projector and frame counter for use in analyzing time-lapse films is discussed in "Photographic Analysis for Construction Operations" and "Construction Methods Improvement by Time-Lapse Movie Analysis" both by John Fondahl, and also discussed in the article by Howard Sprinkle, "Analysis of Time-Lapse Construction Films." Thus, it is possible to obtain activity durations from time-lapse films, but not with the equipment used for this project.

The use of time-lapse photography posed other problems in obtaining activity durations for input into the CYCLONE model. The major problem was finding a suitable vantage point from which to film the span erection procedure. The work was occurring above ground level and the camera was set up at ground level for the filming. The same result occurred as when using stopwatch studies from ground level; certain activities were obscured from the camera's view, although in this case, the camera is more stationary than an observer. Another problem was the limited area which could be viewed by the camera. The camera had to be set back far enough from the work so as to not be in the way, but also so it could view the span currently under construction. With the camera in position to record the activity on one span, it was unable to view the preceding and following piers where the relocation of the support brackets was in progress. Also, in this position the camera could not pick up the level of detail required for certain active states of the CYCLONE model such as install PVC, install strands, and others which were at least partially obscured from view. Another factor to consider in the use of time-lapse photography is the time required to have the film developed. In the case of the two films made during the course of this project, one required over a week to be developed and returned, while the second film required three weeks. The film had to be sent to the Kodak Company in Rochester, New York for processing, thus the long delay in having the films returned. The use of video equipment in lieu of time-lapse photography would eliminate the long wait for film to be processed.

As discussed above, problems were encountered in obtaining activity durations using the stopwatch method and time-lapse photography. Since adequate time data was not obtained from field observatins, estimates of activity durations were obtained from PB/T personnel and utilized in running the MICROCYCLONE program.

In retrospect, considering the construction process which was observed, use of the stopwatch method would allow activity durations to be obtained easily for the CYCLONE active states (see Figure 14) of: "LOAD SEG," "TRK BCYCLE," "LEVEL SEG," "LOWER TRUSS," "MOVE TRUSS," and "MOVE BRAC." Time data for the other activities: "INSTALL PVC," "INSTALL STRD," "POST TEN," and "GRT PAD" would be more difficult to obtain; however, by being able to move freely about the job site, one could obtain this information.

As to use of time-lapse photography applied to the construction process described in this paper, with the proper equipment, time data could be easily obtained for the CYCLONE activities of: "LOAD SEG," "TRK BCYCLE," "LOWER TRUSS," and "MOVE TRUSS." The other activities were either not within the field of view of the camera, were at least partially obscured, or were too far away to obtain the detail desired for accurate activity durations. However, the use of several strategically-placed cameras could record the various activities concurrently from different locations. Activity durations could then be obtained by analyzing the several films. This, however, could prove too tedious and costly.

CHAPTER V

CONCLUSIONS

The use of stopwatch studies was compared to the use of time-lapse photography to evaluate their usefulness as a means of gathering activity durations of on-going construction work for input into a CYCLONE computer model. In spite of the problems encountered in obtaining field data due to class schedules, inclement weather, and construction delays, it is belived that the information gathered and the insight gained from using the time-lapse camera and stopwatch studies, provide an adequate basis on which to reach some general conclusions.

Both methods, stopwatch studies and time-lapse photography, are useful in obtaining time data in the field. Stopwatch studies can provide "instant" information at the end of one day's activity, while time-lapse film must be developed and then analyzed to obtain time data. Time-lapse film does provide a visual record of construction operations which can be used again and again to pinpoint activity times.

In observing the erection of aerial spans involving precast post-tensioned segments, the ability to move around the construction site to observe activities at any point in time provides an advantage to stopwatch studies over the use of a stationary time-lapse camera. It is also believed that activities of a small duration, especially involving hand work, or located in partially obstructed areas, are better observed and durations obtained through the use of stopwatch studies. Time-lapse photography, if used to obtain construction activity durations, appears to be better suited to earthmoving operations or similar operations which are simple in nature, are easily viewed from a distance, and do not require detailed hand work.

The precast segmental aerial construction observed for this study involved a repetitive process of erecting overhead spans. Although on paper it appears to be a smooth, well oiled process, in the field there are situations which occur to slow down the work. The more involved and complex a construction process is, the better the chance for a unique problem to occur which could affect the production cycle. Examples of this which were observed include: (1) once when lowering the span after post-tensioning, the span would not fit down on the anchor bolts on one pier; (2) the man-lift became stuck directly in the path of the crane while the crane was attempting to move the trusses; (3) the support wheel on one end of the truss did not provide adequate clearance during one move. All of these unique problems delayed the span erection.

The use of time-lapse photography would record these delays if they were in the field of view of the camera; however, the film may provide little insight into the cause of delays. An observer using the stopwatch method of recording time data would be able to note the cause of the delays.

A major limiting factor with the use of time-lapse photography is the limited field of view of the camera. If positioned at too great a distance from the work, certain activities can be obstructed from view or not captured in the detail necessary to adequately determine the exact beginning and ending times for activity durations.

Some knowledge of photography is useful in using time-lapse films. Setting the correct film exposure for the activity being filmed will eliminate shadowy areas in the picture and provide a sharper, clearer picture. This is especially needed were hand work is involved in the activity being filmed.

Although it is possible to use time-lapse photography to obtain activity durations, from the study conducted on the erection of precast segmental spans, the problems encountered suggest that stopwatch studies are a more effective means of gathering time data for this type of operation.

The use of CYCLONE modeling as a means of improving construction productivity in the field is better utilized when activity durations can be quickly determined and input into the computer. Thus stopwatch studies have an advantage over time-lapse photography in this situation. Likewise, if there is no urgency in obtaining the activity durations, and manpower is not available to be used for observing the construction activity, then a time-lapse camera can be utilized to record the data and the film analyzed at a later time to obtain the activity durations.

Although estimated activity durations obtained from experienced field personnel were utilized for input into the MICROCYCLONE computer program, the computer simulation process is considered a valid tool in determining construction productivity. The use of CYCLONE modeling requires one to think through the entire construction operation and by graphically displaying the construction processes involved, one is able to get a better understanding of what is occurring on the job site. By obtaining activity durations and inputting the data into the computer, productivity analysis can be realized without having to wait for days or weeks to go by in order to reach some sort of "steady state" operation on the job site. Modeling the construction operation and simulating it on the computer provides a "steady state" operation.

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APPENDIX A

MICROCYCLONE COMPUTER INPUT FOR "SEGMENT"

```
****************************************

*              MICROCYCLONE            *

*                  BY                  *
*           DANIEL W. HALPIN           *
*     THIS PROGRAM IS COPYRIGHTED BY   *
*          D.W. HALPIN  1982           *
*                                      *
****************************************
*                                      *
*      USE OF THIS PROGRAM WITHOUT     *
*      A PROPER LICENSE IS FORBIDDEN   *
*  FOR LICENSING INSTRUCTIONS CONTACT  *
*  D.W. HALPIN,1655 HARBOUR OAKS DR.   *
*       TUCKER. GEORGIA 30084          *
*          TEL:404-939-9587            *
*                                      *
****************************************
* THIS COPY IS NO. 112 REGISTERED TO   *
* DEPT. OF C. E  OHIO STATE UNIVERSITY *
*     COPYRIGHT BY D.W. HALPIN 1982    *
HIT 'RETURN' TO CONTINUE

****************************************
          MODULE: INPUT/CYC

****************************************
DO YOU HAVE ANY INPUT FILE ? Y-YES  N-NO)
ENTER YOUR FILE NAME: SEGMENT

     INPUT MODULE MENU

1. DATA ENTRY
2. ADD
3. DELETE
4. EDIT
5. DISPLAY
6. SAVE FILE
7. SIMULATE
8. END


ENTER YOUR SELECTION: 5
HERE IS YOUR FILE:

LINE # 1: CONTROL

LINE # 2: NAME SEGMENT CYCLES 10 LENGTH 10000

LINE # 3: NETWORK INPUT

LINE # 4: 1 COMBI 'LOAD SEG' SET 1 FOL 3 4 5 PREC 2 5 36

LINE # 5: 2 QUE 'SEG AVAIL'
```

```
LINE # 6: 3 NORMAL 'TRK BCYCLE' SET 2 FOL 2

LINE # 7: 4 FUN FOL 6 10 CON 10

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 8: 5 QUE 'CRANE AVAIL'

LINE # 9: 6 QUE 'START LEVEL'

LINE # 10: 7 QUE 'CREW 1'

LINE # 11: 8 COMBI 'LEVEL SEG' SET 3 FOL 7 9 PREC 6 7

LINE # 12: 9 QUE 'SEG LEVEL'

LINE # 13: 10 QUE 'START PVC'

LINE # 14: 11 QUE 'CREW 2'

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 15: 12 COMBI 'INSTALL PVC' SET 4 FOL 11 13 14 PREC 10 11 13

LINE # 16: 13 QUE 'PVC AVAIL'

LINE # 17: 14 QUE 'PVC OK'

LINE # 18: 15 QUE 'STRD AVAIL'

LINE # 19: 16 COMBI 'INSTALL STRD' SET 5 FOL 11 15 17 PREC 11 14 15

LINE # 20: 17 QUE 'STRD OK'

LINE # 21: 18 QUE 'CREW 3'

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 22: 19 COMBI 'POST TEN' SET 6 FOL 18 20 21 PREC 9 17 18 20

LINE # 23: 20 QUE 'HYD PUMP'

LINE # 24: 21 QUE 'SPAN AVAIL'

LINE # 25: 22 COMBI 'GRT PAD' SET 7 FOL 7 23 24 PREC 7 21 23

LINE # 26: 23 QUE 'GRT AVAIL'

LINE # 27: 24 QUE 'PAD OK'

LINE # 28: 25 COMBI 'LOWER TRUSS' SET 8 FOL 11 26 27 PREC 11 24 26

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 29: 26 QUE 'HYD JACK'

LINE # 30: 27 FUNCTION COUNTER QUANTITY 1 FOL 28
```

```
LINE # 31: 28 QUE ' SPAN IN PLACE'

LINE # 32: 29 COMBI 'MOVE TRUSS' SET 9 FOL 5 31 36 PREC 5 28 30

LINE # 33: 30 QUE 'BRAC AVAIL'

LINE # 34: 31 QUE 'BRAC TO MOVE'

LINE # 35: 32 COMBI 'MOVE BRAC' SET 10 FOL 30 33 34 35 PREC 31 33 34 35

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 36: 33 QUE 'MANLIFT'

LINE # 37: 34 QUE 'CREW 4'

LINE # 38: 35 QUE 'CH PKER AVAIL'

LINE # 39: 36 QUE GEN 10 'TRUSS AVAIL'

LINE # 40: EQUIPMENT INPUT

LINE # 41: 3 'SEGS' AT 2

LINE # 42: 1 'CRANE' AT 5

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 43: 1 'CREW 1' AT 7

LINE # 44: 1 'CREW 2' AT 11

LINE # 45: 1 'PVC' AT 13

LINE # 46: 1 'STRD' AT 15

LINE # 47: 1 'CREW 3' AT 18

LINE # 48: 1 'HYD PUMP' AT 20

LINE # 49: 1 'GRT' AT 23
```

```
RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 50: 1 'HYD JACK' AT 26

LINE # 51: 1 'TRUSS' AT 36

LINE # 52: 1 'BRAC' AT 31

LINE # 53: 1 'CH PKER' AT 35

LINE # 54: 1 'CREW 4' AT 34

LINE # 55: 1 'MANLIFT' AT 33

LINE # 56: DURATION INPUT

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 57: SET 1 120

LINE # 58: SET 2 40

LINE # 59: SET 3 120

LINE # 60: SET 4 120

LINE # 61: SET 5,90

LINE # 62: SET 6 60

LINE # 63: SET 7 120

RETURN TO LAST PAGE - R ...OR CONTINUE - C?
LINE # 64: SET 8 30

LINE # 65: SET 9 90

LINE # 66: SET 10 420

LINE # 67: ENDDATA
```

APPENDIX B

MICROCYCLONE REPORT

"PRODUCTION BY CYCLE STEADY STATE REPORT"

****
STEADY STATE REPORT

****

SIM TIME	CYC NUMBER	PRODUCTIVITY
925	1	1.08108108E-03
1887	2	1.05988341E-03
2849	3	1.05300105E-03
3811	4	1.04959328E-03
4773	5	1.04755919E-03

M-MAIN MENU R-REPEAT LAST PAGE C-CONT
?M
M**

APPENDIX C

MICROCYCLONE REPORT

"PROCESS REPORT"

```
***************************************
     PROCESS REPORT     NAME: SEGMENT

***************************************
HOURLY PRODUCTION AND COST BASED ON HOW MANY MINUTES/HR?
INPUT NO. OF MIN/HR            - 60
***************************************
     PROCESS REPORT     NAME: SEGMENT

***************************************
RUN LENGTH                     10020
COUNT ON FUNCTION COUNTER      5
UNITS PRODUCED PER CYCLE       1
TOTAL PRODUCTION               5
UNITS PRODUCED PER UNIT
OF TIME (I.E. PER MINUTE)      4.99001996E-04

***************************************
     COST SUMMARY DATA

***************************************
HOURLY PRODUCTION              .0299401198
TOTAL COSTS (VAR+FIXED)       $0
COST PER UNIT                 $0
```

APPENDIX D

STOPWATCH STUDY FIELD DATA

MARTA SOUTH LINE

(near Oakland City Station)

PROJECT : MARTA CONTRACT CS-360 (SOUTH LINE)
LOCATION : NEAR OAKLAND CITY STATION
DATE : 8 MARCH 1983

ITEM	WORK ACTIVITY	TIME (HR: MIN: SEC) START	FINISH
1	CREW POST TENSIONING SEGMENTS	10 50: –	—
2	CREW BOLTING BRACKETS TO PIER 60	10 50: –	—
3	CREW POSITIONING ROLLERS ON TRUSS	11 08: –	—
4	CRANE MOVE RR SIDE TRUSS	11 23: –	11 37: –
5	CREW REMOVING EQUIP FROM PIER 60	11 23: –	—
6	CREW HOOK UP HYD TRUSS JACKS	11 37: –	—
7	CRANE MOVE ROAD SIDE TRUSS	11 39: –	11 53: –
8	LUNCH FROM 1200 – 1230	—	—
9	CREW SECURING TRUSSES	12 33: –	—
10	CHERRY PICKER LIFTING PADS TO PIER 59	12 38: –	—
11	CREW REMOVING BRACKETS FROM PIER 58	12 45: –	15 30: –
12	CH. PICKER LIFTING PADS TO PIER 60	12 45: –	—
13	CRANE LIFTING WORK PLATFORM PIER 60	12 47: –	12 53: –
14	CREW SECURING TRUSSES AT PIER 60	12 50: –	—
15	SEG LIFTING FRAME HOOKED TO CRANE	12 55: –	—
16	SEG #1 ARRIVES ON TRUCK	12 58: –	—
17	SEG #2 ARRIVES ON TRUCK	13 00: –	—
18	FRAME ATTACHED TO SEG #1	13 01: –	—
19	SEG #1 OFFLOADED & PLACED ON GRND	13 04: –	—
20	SEG #3 ARRIVES ON TRUCK	13 07: –	—
21	CREW PREPARE ROLLERS & SHIMS (ROAD TRUSS)	13 14: –	13 19: –
22	CABLE ATTACHED TO ROLLERS	13 20: –	—
23	CREW PREPARE ROLLERS & SHIMS (RR TRUSS)	13 38: –	13 44: –

PROJECT : MARTA CONTRACT CS-360 (SOUTH LINE)
LOCATION : NEAR OAKLAND CITY STATION
DATE : 8 MARCH 1983

ITEM	WORK ACTIVITY	TIME (HR: MIN: SEC) START	TIME (HR: MIN: SEC) FINISH
24	CRANE LIFT & PLACE SEG # 1	13 44: —	13 50: —
25	SEG # 4 ARRIVES ON TRUCK	13 50: —	—
26	FRAME ATTACHED TO SEG # 2	13 52: —	—
27	SEG # 1 ROLLED INTO PLACE	13 53: —	—
28	CRANE LIFT AND PLACE SEG # 2	13 54: —	13 57: —
29	SEG # 2 ROLLED INTO PLACE	13 57: —	14 01: —
30	CRANE LIFT & PLACE SEG # 3	13 59: —	14 03: —
31	FRAME ATTACHED TO SEG # 4	14 05: —	—
32	SEG # 3 ROLLED INTO PLACE	14 05: —	14 07: —
33	CRANE LIFT & PLACE SEG # 4	14 06: —	14 09: —
34	SEG # 4 ROLLED INTO PLACE	14 09: —	14 11: —
35	SEG # 5 ARRIVES ON TRUCK	14 13: —	—
36	CRANE LIFT & PLACE SEG # 5	14 17: —	14 20: —
37	SEG # 6 ARRIVES ON TRUCK	14 20: —	—
38	SEG # 5 ROLLED INTO PLACE	14 21: —	14 22: —
39	CRANE LIFT & PLACE SEG # 6	14 24: —	14 27: —
40	SEG # 7 ARRIVES ON TRUCK	14 26: —	—
41	SEG # 6 ROLLED INTO PLACE	14 27: —	14 28: —
42	CRANE LIFT AND PLACE SEG # 7	14 30: —	14 33: —
43	SEG # 8 ARRIVES ON TRUCK	14 32: —	—
44	SEG # 7 ROLLED INTO PLACE	14 33: —	14 34: —
45	CRANE LIFT AND PLACE SEG # 8	14 36: —	14 39: —
46	SEG # 9 ARRIVES ON TRUCK	14 39: —	—

PROJECT: MARTA CONTRACT CS-360 (SOUTH LINE)
LOCATION: NEAR OAKLAND CITY STATION
DATE: 8 MARCH 1983

ITEM	WORK ACTIVITY	TIME (HR: MIN: SEC)	
		START	FINISH
47	SEG #8 ROLLED INTO PLACE	14 39:—	14 39:—
48	CRANE LIFT & PLACE SEG #9	14 44:—	14 47:—
49	SEG #9 ROLLED INTO PLACE	14 47:—	14 47:—
50	CREW LEVEL & ALIGN SEGS	14 50:—	—
51	CREW POSITIONING STRANDS ON SPAN 60	14 50:—	15 00:—
52	CH. PICKER MOVE ONE BRACKET (PIER 59 TO 61)	14 54:—	—
53	CREW INSTALL PVC SPAN 60	15 00:—	—
54	CREW INSTALL STRANDS SPAN 60	15 29:—	—
55	CREW RELOCATE FROM PIER 58 TO 60	15 33:—	—
56	KNOCK OFF WORK AT 1550	—	—

APPENDIX E

STOPWATCH STUDY FIELD DATA

MARTA NORTH LINE

(near Lenox Station)

PROJECT: MARTA CONTRACT CN-480 (NORTH LINE)
LOCATION: NEAR LENOX STATION
DATE : 3 MAY 1983

ITEM	WORK ACTIVITY	TIME (HR:MIN:SEC) START	TIME (HR:MIN:SEC) FINISH
1	CRANE LIFT GENERATOR TO SPAN 2	07 40:00	07 41:53
2	CREW WORK ON BRACKETS PIER 3	07 40:00	07 49:15
3	CREW CUTTING & POSITIONING STRANDS	07 48:40	08 08:10
4	CRANE LIFT [illegible] TO PIER 2	[illegible]	[illegible]
5	CRANE LIFT CABLE SPOOL TO SPAN 2	08 13:[illegible]	08 1[illegible]
6	CRANE REPOSITION SPOOL ON SPAN 2	[illegible] 17:35	08 18:[illegible]
7	CRANE LIFT BEARING PADS TO PIER 2	08 20:20	08 29:52
8	CRANE MOVE RR SIDE TRUSS	08 31:00	—
—	PROBLEMS DEVELOPED - UNHOOKED TRUSS	FROM CRANE	W/OUT MOVING
—	IT AT 0843:30		
9	"ROACH COACH" ARRIVED - ALL WORK	STOPPED	FOR A BREAK
—	FROM 0844 - 0856		
10	CRANE MOVE RR SIDE TRUSS	08 59:30	10 00:[illegible]
11	CRANE MOVE ROAD SIDE TRUSS	10 01:45	10 25:03
12	CREW HOOK UP HYD TRUSS JACKS PIER 3	10 03:00	10 05:40
13	CREW PREPARE TO SECURE TRUSSES	10 06:35	10 07:45
14	CREW HOOK UP HYD TRUSS JACKS PIER 2	10 25:05	10 27:30
15	CREW SECURE TRUSSES PIER 3	10 25:45	10 28:50
16	CREW SECURE TRUSSES PIER 2	10 29:45	10 33:50
17	CRANE PLACING WORK PLATFORM PIER 3	10 31:30	10 36:32
18	JACK TRUSSES INTO POSITION	10 39:30	11 02:00
19	SEGMENT LIFTING FRAME HOOKED TO CRANE	11 02:41	11 05:50
20	CRANE LIFT AND PLACE SEGMENT #1	11 06:34	11 32:45

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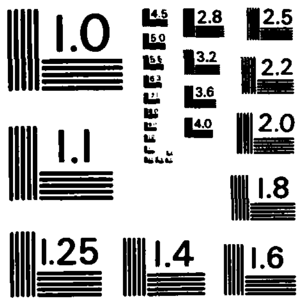

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NATIONAL 42-383

PROJECT : MARTA CONTRACT CN-480 (NORTH LINE)
LOCATION : NEAR LENOX STATION
DATE : 3 MAY 1983

ITEM	WORK ACTIVITY	TIME (HR: MIN: SEC)	
		START	FINISH
21	CREW PREPARE TO LEVEL & ALIGN SEGS	11 33:30	—
22	LUNCH FROM 1200 - 1230	—	—
23	CREW CUTTING STRANDS FOR USE	12 35:00	—
24	WELDING REPAIRS BEING MADE ON TRUSS	NO MOVE	
—	SEGMENTS UNTIL REPAIRS MADE.	—	—
25	RAIN AT 1300 - WORK STOPPED FOR THE DAY -		

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